DEVELOPMENT OF A GENERALIZED DIGITAL SIMULATOR FOR PRODUCTION SYSTEMS

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By
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to the

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TO

MA and PA

CERTIFICATE

This is to certify that the work "Development of a Generalized Digital Simulator for Production Systems" by Vasant R. Shroff has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

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SYNOPSIS

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"Development Of a Generalized Digital Simulator For Production Systems"

In this study a computer simulator has been developed to facilitate the planning and control of the production systems. The proposed simulator has capabilities to handle various production planning and control functions e.g., sales forecasting, inventory control, etc. The production system under study is simulated over a planning horizon to generate a set of decision rules. These decision rules provide guidelines for the production manager to take logical decisions. As such the simulator can handle a production situation where fifteen work stations, fifty components and three finished products are involved. This restriction has been imposed keeping in view the capabilities of IBM 7044 computing system. The simulator has been validated with the help of data collected from an electronic industry manufacturing television sets.

CHAPTER I

INTRODUCTION

Production Management is the art of achieving the four basic aims of management - i) the right product, ii) at the right time, iii) at the right cost and iv) at the right place. The achievements of these goals can be made possible only by a proper coordination of planning and control of the production system. The primary function of production planning and control activity is to design a sound framework within which a set of inter-related decisions can be satisfactorily made. This necessitates the design of control mechanism incorporating the following ingradients (1) :

1. A current operation plan to specify the desired performance of the manufacturing system in terms of meaningful effectiveness criteria.
2. A data acquisition system to determine, on a timely and accurate basis, the current status of the manufacturing system.
3. A method of comparison of the actual results with the desired goal.
4. The corrective action to activate the goal seeking effort.

The last two are the manifestations of the feed-back loop concept. The inherent complexities of the real system make the

design of control systems a difficult task. However, many research workers and production managers have attempted to design idealized control systems, keeping in view the needs of individual industries (1, 2). But, unfortunately very few efforts have been directed towards the control of real life production systems.

Efforts of various research workers in the field of production planning and control has helped the industries to design integrated control systems for individual's requirements. But, in Indian industries even the basic concepts of production planning and control are not in vogue. The present work aims at developing a production planning and control system for an Indian industry. The model has been developed and validated for the manufacture of Television Sets at J.K. Electronics. The particular production situation was selected because of the following advantages :

1. Availability of accurate and timely data.
2. A mathematical model can be easily structured, because the size of the system is neither too big nor too small.
3. Since the manufacture of TV sets involves a continuous assembly line, the interactions of various elements within the system are easy to identify and evaluate.
4. At present the production managers of TV industries in India are faced with an uphill task of systematic design of production planning and control systems to

meet the heavy demand of the product in the country and abroad. It is one of the fast expanding industries which requires careful attention on the part of the management.

Traditionally two basic approaches have been employed by the industries to design the production control systems. One way is the ordinary individual control function approach in which several control functions are treated individually. Another way is the case - study approach in which a similar real or hypothetical system is analyzed. Both the approaches suffer on account of several drawbacks (3) :

1. Analysis is given more emphasis compared to the design.
2. They do not consider the dynamic nature of the production environments.
3. A comprehensive understanding of the whole production control system is lacking - the interactions are either undefined or not well defined.
4. The cause-effect relationship of decisions is not incorporated and thus lack in evolving corrective action. Further, the feed back concepts have not been given adequate representation.
5. The role of management information systems in control has either not been realised or not stressed.

Most of these drawbacks are offset in a third and comparatively new technique - the computer simulation. Simulation is the process of conducting experiments on the model of a system in lieu of either direct experimentation with the system itself, or direct analytical solution of some problems associated with the system. Thus, with a set of alternatives in hand, simulation can be resorted to, in order to study the system's behaviour and make pertinent decisions about the choice of the alternatives. However, simulation does not necessarily pinpoint optimum solutions, but it generates a response curve on which the optimum lies (4).

The present work consists in the development of a production planning and control simulator for an Indian industry. A thorough search of the literature indicates that very few computer simulators have been developed by various research workers for pedagogic purpose (3, 5, 16, 17). More prominent amongst those extensively used is, PROSIM V - Production System Simulator (11). It has been successfully used by the instructors and research workers as an effective teaching aid in the field of production control. But, the simulator has basically been designed to examine the knowledge of the students in designing production control systems. It is used as a tool to evaluate the various decisions made by the user, but it does not provide guidelines to arrive at those decisions. It is a general purpose simulator which can be utilised for different simplified production systems.

In the present work, the PROSIM V simulator has been modified considerably so as to represent the mathematical model of the real life production system under study. The model has been developed for the aforementioned industry with the basic objective of designing a control system that will provide the production manager with decision policies which, on implementation in the long run, will result in minimum cost of production. The production planning and control system encompass the following functions : (a) Forecasting, (b) Operations Planning, (c) Inventory Planning and Control, (d) Operations Scheduling and (e) Dispatching and Progress Control. The decision making mechanism covers the above functions and also takes into account the interactions amongst the various system elements e.g. different products, raw materials, work stations, men, etc. to provide optimum decision policies to the decision - maker.

In order to simplify the mathematical formulation of the model, appropriate assumptions have been made in the system, as and when necessary. The model has been tested using the data collected from J.K. Electronics for only one particular product out of several products manufactured by the said industry. Although the production planning and control simulator presented here has been primarily developed and tested for a television industry, every care has been taken to make it general purpose simulator. The same simulator, with minor modifications, can be adapted for any other production situation without much difficulty.

CHAPTER II

LITERATURE REVIEW

As was stated in the previous chapter the use of computer simulation, as a technique for designing of production control system, is still in its infancy. However, in the past efforts for the development of production planning and control simulators have been made by educational institutes. In this chapter a review of the various educational production simulators and their applications to the real life production systems has been made.

2.1 Educational and Teaching Efforts

Currently a lot of interest is being shown in the use of computer simulation as an aid in teaching concepts of industrial engineering, production management and operations research. Computer simulation has also been used successfully for studying higher-order relationships between major components of a firm and between competing firms. One of the first efforts in pedagogical simulation was the work on Industrial Dynamics by J.W. Forrester (6). Forrester developed a computer language DYNAMO (DYNAMIC MODELS), with the capacity to account for interactions amongst system elements and the economics of the entire industry.

Roberts (8) used Industrial Dynamics philosophy for the control of the research and development projects. DYNAMO has been used to evaluate and predict dynamic behaviour of production - inventory systems with changes in market demand and other factors (6, 9).

Several simulators have been developed for "management games". Perhaps the most comprehensive of these is the Carnegie Tech. Management Game (5). 'Management games' are concerned with the production system only in a gross way. They are used primarily for training purposes (10).

Porter et. al. (11), Vollman (12), and Whiteman and Love (13) have used simulation as a teaching aid in Industrial Engineering. One of the latest efforts in this field being that of Greenlaw and Hottenstein (7). They have integrated the works of Porter, Vollman, Whiteman et. al. (11, 12, 13) and other techniques of production management (14, 15, 16, 17) to develop a computerized production management simulator known as PROSIM (PRODUCTION MANAGEMENT SIMULATION).

As compared to DYNAMO and the management games PROSIM stands out on account of the following reasons :

1. DYNAMO simulates the system with a macro-view, while in PROSIM a micro-view is followed by considering the hourly events in the simulated production system.

2. While DYNAMO is capable of simulating a complete industrial system or entire economy, it treats production system as a single component in the total simulated system. PROSIM emphasizes centrally on the production system and generates relationship with the environment.

3. Unlike the various management games which are concerned with the production system only in a gross way, PROSIM can be used

as a management game emphasizing the production system in details.

Owing to the above mentioned advantages the PROSIM model has been widely used by production management students and research workers at the Pennsylvania State and other universities. Computer program written in FORTRAN* has been developed for PROSIM model for two different IBM systems - the 700/7000 and 360 series. This computer package can be easily used by instructors having little or no knowledge of computer programming.

2.1.1 PROSIM Model

The fundamental objective of PROSIM is to facilitate the learning and the mastery of certain basic concepts and techniques of production management by the participant. In keeping with the above, the participant is provided with a simulated environment wherein he can make decisions and study their effects. In accordance with the objective, decision problems in other functional areas of the business firm e.g. marketing and finance, have been included in the model only to the extent that they bear relevance to production management.

The model has been designed so that the decision problems faced by the participant, possesses many of the same fundamental characteristics as those faced by real world production managers. PROSIM is capable of simulating an enterprise, manufacturing at most three different products (X, Y, and Z respectively). The manufacturing operation is assumed to be comprising of two production lines

*FORTRAN and FORTRAN IV are used interchangably in this text.

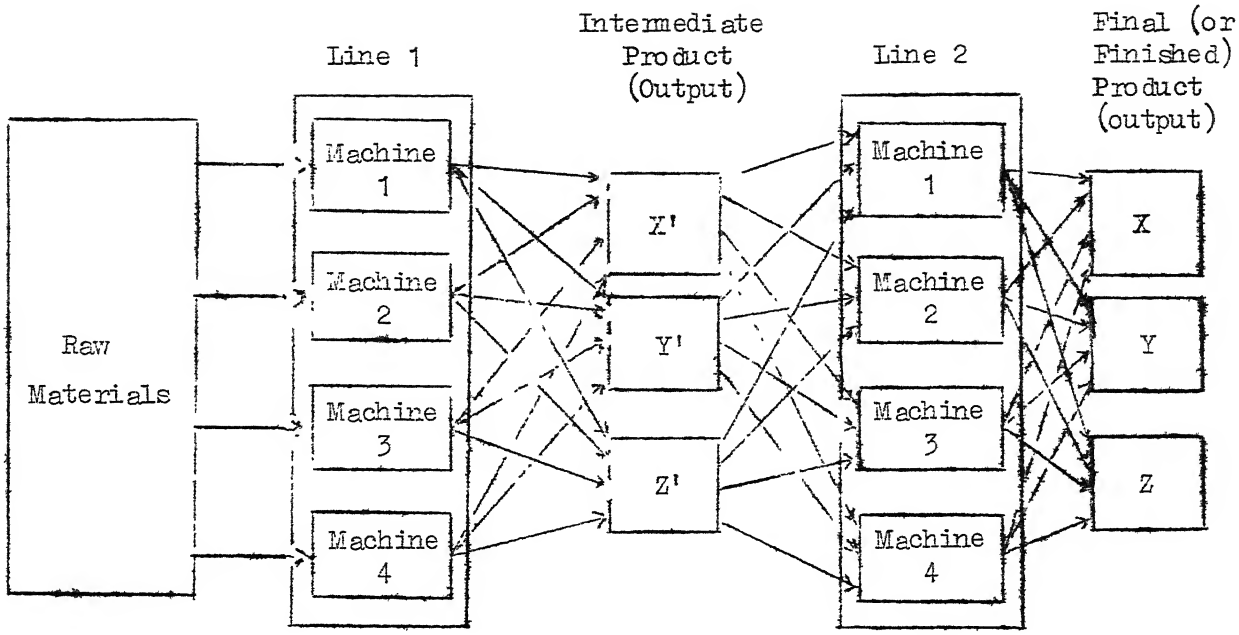

FIGURE 1

THE PROSIM MANUFACTURING PROCESS*

each of which consists of four identical machines as shown in Figure 1. Each of the three products require processing on each of these two lines. Raw materials are first fabricated into unfinished products on line 1, referred to as X', Y' and Z'. Then these are converted into finished products on line 2.

The participant has to make numerous inter-related decisions during each period of simulation, i.e. a day. Two fundamental types of relationships exist in the model, as is illustrated graphically in Figure 2 :

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*Derived from "PROSIM : A Production Management Simulation" by Greenlaw, P.S. and M.P. Hottenstein; page 6.

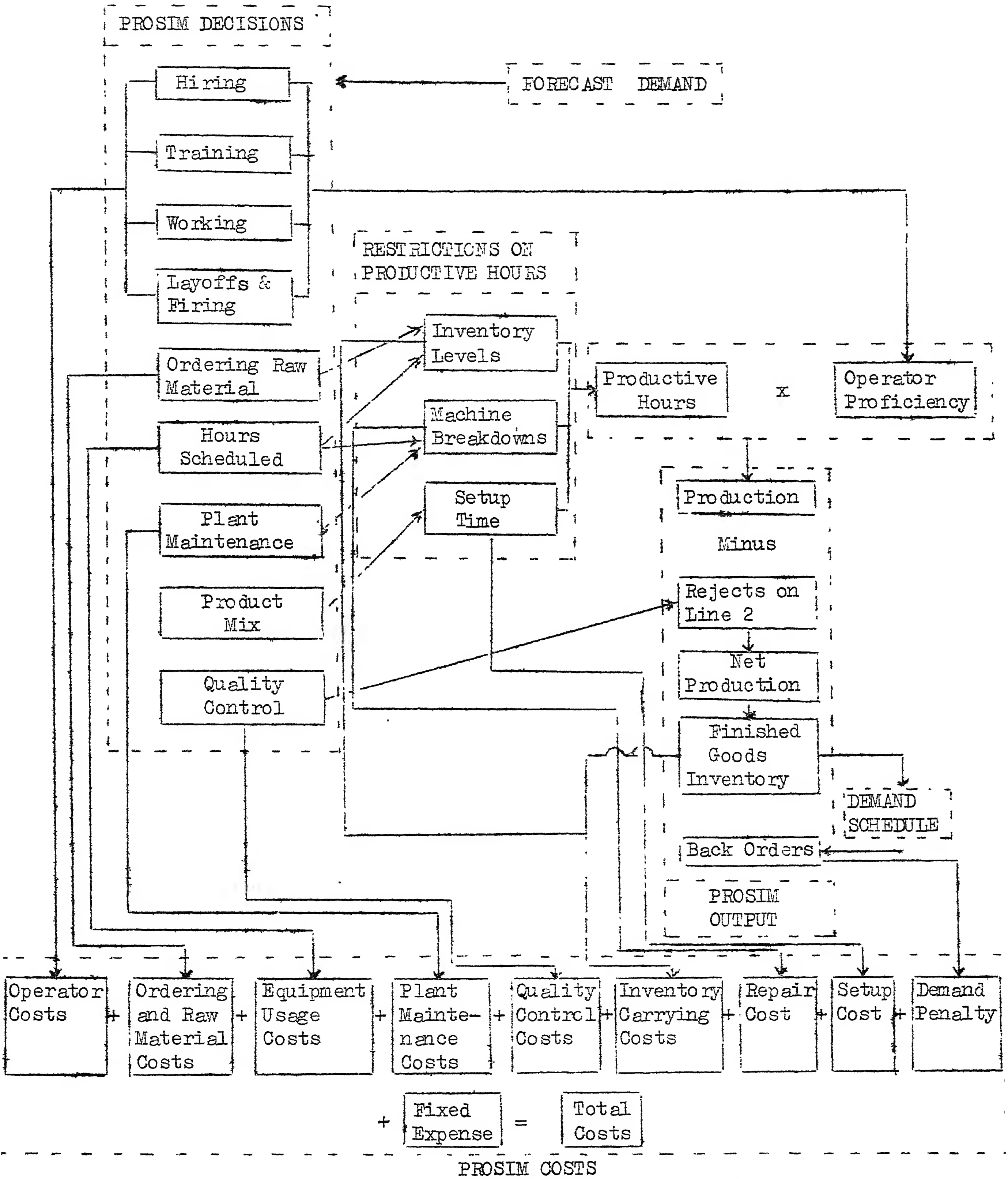

FIG. 2 : BASIC PROSIM RELATIONSHIPS (Derived from "PROSIM : A Production Management Simulation" by Greenlaw, P.S. and M.P. Hottenstein; page 50.

1. The participant's decisions will determine the number of units of output of finished goods to be produced by the firm in order to meet its demand schedules.

2. The same decisions will also determine the costs incurred during each period of the simulation.

To arrive at these sets of decisions, the PROSIM participant has to decide his objectives and subobjectives. The main objective in the model is that of minimizing the total costs involved in operating the system in the long run. The term "long run" is important since in many cases it may be necessary for the firm to incur additional costs in one period in order to avoid even larger costs in future periods. The cost approach is followed because the cost can be measured much more accurately than the profit, especially at the subsystem level.

In order to meet the basic objective, numerous subobjectives have to be established. For example, keeping inventory costs under control, meeting the demand schedules, products assignment to machines for minimum set-up costs etc. The PROSIM participant decides as to (i) how such sub-objectives ought to be formulated and (ii) how various measures of performance of the system may be developed.

The final decisions which the PROSIM participant makes to satisfy previously mentioned objectives are as follows (Figure 2):

1. Quality control expenditures.
2. Plant maintenance expenditures.

3. Regular raw materials order in units.

4. Expedited raw materials order in units.

5. Scheduling the operators on the machines.

6. Decision for training the operator.

7. Product scheduling on various machines.

8. Time scheduling of various machines in hourly units.

PROSIM model incorporates the various performance - measures and sets of decision rules in order to facilitate achievement of the above aims (17). Most of these decision rules are complex and inter - related. Various mathematical techniques are attempted in the model e.g. the technique of dynamic programming has been used for planning the production for short term.

Greenlaw and Hottenstein (7) have developed a number of data - forms to be filled in by the participant to arrive at his final decisions. This reduces the number of computations and provides guide-lines to the participant in making final decisions. After feeding these final decisions as data in PROSIM computer simulator, the participant receives a computer printout providing following informations relative to its operations, for each simulation period : (i) cost information, (ii) product information, (iii) inventory information, and (iv) demand information.

Although there are many thousands of combinations of decisions which may be made in each period, the PROSIM participant is constrained in his choice of strategies. The generation and evaluation

of decision strategies is restricted due to limited planning horizon.

In the PROSIM model the problem of optimization with respect to the attainment of various objectives is left unsolved, that is, one objective may be more fully met only at the expense of lesser attainment of another. Also generally no single decision algorithm is available to completely optimize the objective. Due to these complexities in decision making process, the PROSIM participant is generally content to satisfice rather than optimize his objective.

Mize et. al. (13) extended the PROSIM model at Auburn University to develop a production system simulator, PROSIM V, which is capable of simulating a variety of operating environments, including nonmanufacturing operations. While PROSIM simulates the hourly activities of the production system, in PROSIM V each minute event is simulated, making it more accurate. The model incorporates move realistic situations like waiting lines and accounts for the inherent variability in different parameters, such as number of work stations, number of products, etc.

2.1.2 PROSIM V Model

PROSIM V is capable of simulating a production planning and control system consisting of the following functions :

1. Sales forecasting.
2. Operations planning.
3. Inventory planning and control
4. Operations scheduling.
5. Dispatching and progress control.

The model simulates a typical inventory-production - sales system as shown in Figure 3. Such a system usually has the following characteristics :

1. Several finished products, sold in discrete units.
2. Periodic (weekly, monthly, etc.) demand for each product is a random variable and may or may not follow a trend.
3. Each product is composed of assemblied and parts.
4. Atleast some of the assemblies are composed of sub-assemblies and purchased parts.
5. There are some common components and subassemblies among the finished products.
6. Lead time for purchased parts is a random variable.
7. Fabrication and assembly operations are performed at "work stations". A work station is defined as an area where specified work is performed; this may consist of a man and/or a machine, or several men and/or machines.
8. Different assemblies require processing on some of the same work stations.
9. Processing times at all work stations are essentially deterministic.

The above characterstics are typical of many manufacturing systems. A particular system is simulated by initializing pertinent parameters in the computer model.

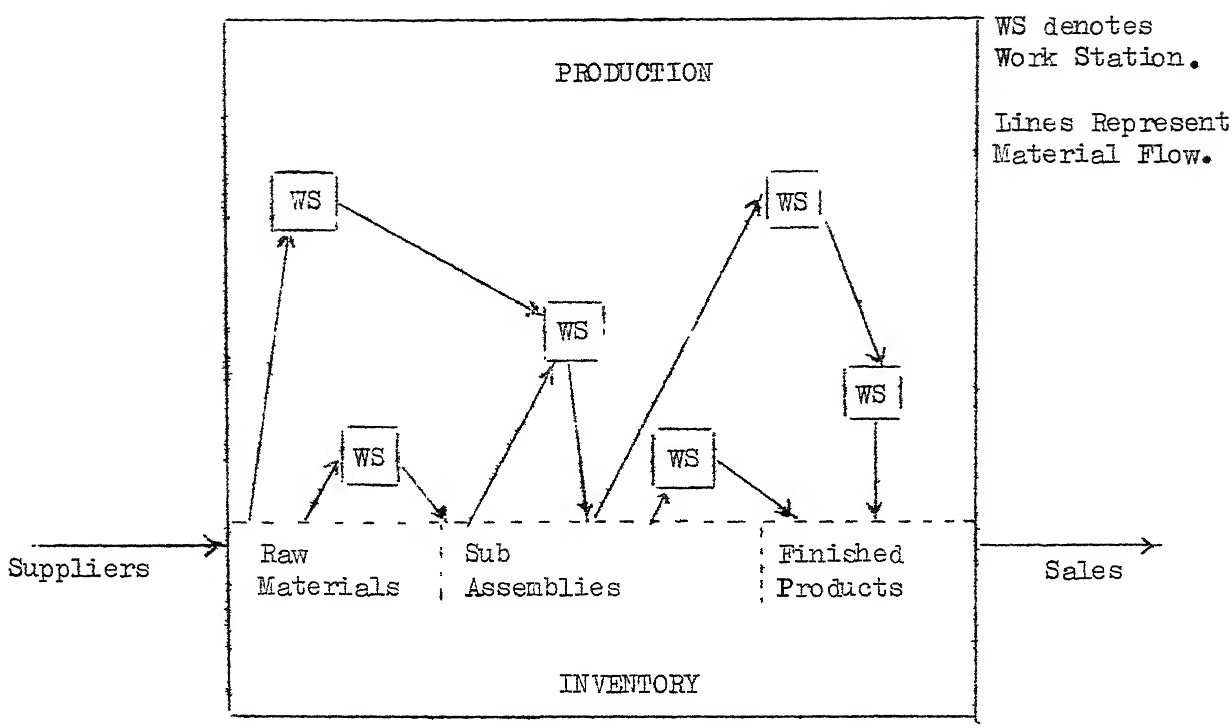

FIGURE 3 : TYPICAL INVENTORY-PRODUCTION-SALES SYSTEM*

Important characterstics of any production simulator are the size of operating system it can simulate and the computer time required for a typical simulation run. In this model these characterstics depend upon the number of work stations, number of finished goods, and the number of stock numbers (a unique stock number is assigned to each finished good, assembly, part, and raw material), in the production system. PROSIM V is limited in the size of the problem it can handle by the size of available computer memory. The computer time required for the simulation depends entirely upon the size of the manufacturing system being simulated and the computational speed of the computer.

* Derived from "PROSIM V Administrator's Manual : Production System Simulator" by Mize, J.H. et. al; page. 6.

Another important characterstic of this kind of simulator is its flexibility. The flexibility of PROSIM V is shown by the following features :

1. The operating period is variable, usually a period of one week is used.
2. Several periods of simulation can be run on one computer run.
3. The time increment is variable. If a time increment other than one minute is used, then all processing and set - up times must be in multiples of the time increment.
4. The lot size is variable. Items may be produced in lots of any integer size.
5. Certain features, such as random demand and random lead time can be turned "on or off" with a parameter card.
6. No more than five work stations may process any one stock number and no more than five raw materials or sub-assemblies may merge into one stock number. This restriction is easily overcome by specifying dummy assemblies.

2.1.2.1 Conceptualization of PROSIM V

In PROSIM V the instructor acts as the Production Manager. He translates a hypothetical manufacturing system into pertinent

parameters and the simulator is initialized. Then the users or students, analyzes this data and designs a preliminary control system to make a set of operating decisions. One set of user's decisions directs PROSIM V through one period of simulated operation.

Production orders for manufactured items and purchase orders are placed only at the beginning of each period. Each production order is immediately released to the first work station that performs work on that item. The new production orders follow a FIFO system. PROSIM V divides the weekly operating period into five equal daily periods. It causes one-fifth of weekly demand to occur instantaneously at the end of each day. It also divides the weekly operating time for each work station by five and sets up five identical days of available operating time.

In PROSIM V a complete record of dynamic inventory is maintained. Whenever the stock on hand of any component reaches a low level, it can be replenished only by instructing the simulator to manufacture or purchase (depending upon the type of item), a certain number of components.

In PROSIM V each work station is assigned a unique identification number. Each manufactured item must be processed on atleast one work station. This processing may or may not require the addition of other stock numbers. The operations network for each item is defined by specifying the sequence of the work stations required to manufacture the item. The same work station may not appear more than once in the same network.

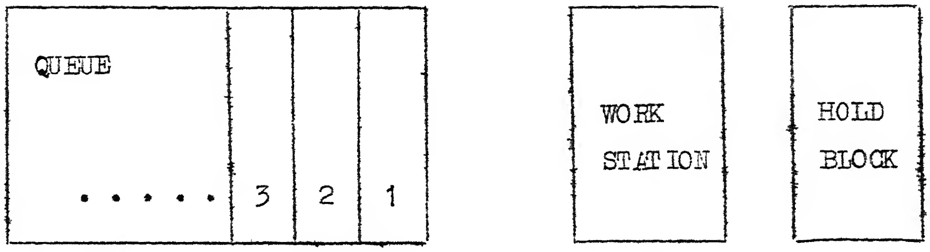

FIGURE 4 : CONCEPTUAL VIEW OF PROSIM V SUBSYSTEM*

Conceptually, a work station is considered as a Queueing Subsystem as shown in Figure 4. The exact number of "queue positions" for each work station is provided as an initialization parameter. A queue position holds one production order, regardless of the size of the order. Queue positions are not used as temporary storage for items needed in the manufacture of production order, all such items are held in inventory. Simulator continuously moves orders forward in the queue. If there are no orders in the queue at a particular time, then the work station goes idle until another order arrives.

PROSIM V processes production orders through work stations in "lots", rather than in individual units. The "lot size" is an initial parameter and remains unchanged throughout the entire simulation. The same lot size applies to all manufactured items. If a product order quantity other than the lot size is ordered, PROSIM V truncates the order to the next lowest multiple of the lot size. A batch quantity is also specified for each manufactured

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*Derived from "PROSIM V Administrator's Manual : Production System Simulator" by Mize, J.H. et. al.; page 17.

item in the initial data. Most items have a batch quantity of one, whereas small items such as screws, nuts, bolts, etc., which are manufactured and used in large quantities may have any desired batch quantity. A "batch" is regarded as a "unit" until it has been processed on the last work station in its network. All processing times on work stations are specified for a "batch" of the particular item.

When a production order for some stock number comes in the first queue position, the simulator checks if the raw material needed to manufacture one lot of the stock number are available in the inventory. If they are available then the production order is moved from queue position one into the work station. The lot remains on the work station for a known length of time (processing time). Simulator moves the processed lot from the work station to the "Hold Block" as shown in Figure 4. A hold block may be regarded as an area adjacent to the work station used to collect a specified number ("hold quantity") of units of an order before sending the units either (i) to the next work station in the network, or (ii) to inventory, if this is the last work station on the network. Simulator then determines whether enough of the raw material needed are available to process another lot of the same stock number. If they are available, another lot is moved from queue position one onto the work station. This process is continued until the entire order is processed or until items shortage is faced.

Whenever a production order with insufficient quantity of raw materials, needed to produce one lot, is encountered the simulator

continues searching the queue for an order that can be processed. The orders with insufficient inventory quantities are moved back in the queue. If no order with sufficient inventory is found, the work station becomes idle until the inventories are available for processing any of the orders in the queue.

Purchased items are received only at the end of a day and are available for use at the beginning of the next day. Manufactured items are added to stock on hand in lots immediately upon the completion of processing at the final work station in the network. These items are available for immediate use, soon after the processing is completed for one lot.

If all queue positions are full at a work station, then processing at the preceding work station in the network stops. It remains idle until the items in the hold block can be moved to the next work station. When a work station has completed processing an order, it is forwarded to the next work station in the network, whether or not the "Hold Quantity" has been reached.

Each production order is assigned a sequential "order number" by the simulator. It is needed in order to keep separated two or more production orders for the same stock number, placed in same or different periods. In same period more than one production order for one item may be placed due to the following reasons : (i) economic production lot sizes, (ii) priority assignment to certain orders and (iii) to force production of "at least a few" of several items in a

period. When an order arrives at a work station for processing, the simulator searches the queue for an order with the same order number, if found it places the order at same queue position. If no such match can be found, the arriving order is assigned the first available queue position.

2.1.2.2 Simulator Initialization

PROSIM V is initialized by providing values of various variables and parameters. Mize et. al. (3) have used the following parameters, pertinent to the manufacturing system being simulated for initialization :

1. Work station network for each manufactured item.
2. Parameters for demand generators (one demand generator for each finished product).
3. Parameters for lead time generators (one lead time generator for each purchased item).
4. Process time and set up time for each manufactured item at each work station.
5. All costs, parameters and constraints pertinent to the simulated system.

PROSIM V user is provided with the following data as a starting point for his analysis :

1. Items 1, 4 and 5 from the preceding paragraph.
2. A demand history for each finished product.
3. Labour and work station rates for each work station,

shift change cost; overhead rate, idle time cost, etc.

4. For each stock number, initial stock on hand, carrying cost, reorder cost, discount order quantity, regular price, discount price, average lead time, out-of-stock-cost, etc.

The user uses the above mentioned data to design his production control system. The following general procedures may be used as a way of getting started :

1. Begin the design of the control system.
2. Analyze the historical sales data and determine the forecasting procedures.
3. Determine the inventory system to be used and the economic order quantity or time interval for each purchased part.
4. Determine the economic batch size for each manufactured item and use this to help determine the hold quantity for each product at each work station, and/or the production order quantity.
5. Determine the point at which it is economical to switch from overtime to another shift for each work station.
6. Analyze the demand trends over a long period of time (say one year) and attempt to "smooth" total production requirements over this period.

The user's control system must lead him to the following decisions for each simulated period :

1. Estimation of demands for all the finished goods.
2. Purchase orders for raw materials.
3. Production orders and desired sequence for manufactured items.
4. Time available for each work station (regular time, overtime, extra shifts).
5. In-process buffer sizes (hold quantities).

2.1.2.3 Simulator Ground Rules

The following "ground rules" govern the manner in which PROSIM V acts upon the user's decisions and simulates the operation of the manufacturing system :

1. Simulator reads the forecasted demand values for finished goods. It then generates an actual demand quantity for the week using demand parameters and the Monte Carlo Sampling (18). To obtain the daily demand, the weekly demand is divided by 5 and the value is truncated. Conceptually demand occurs instantaneously at the end of each day.
2. For each purchase order, a random lead time is generated using parameters (mean lead time and its standard deviation) and Monte Carlo Sampling. Conceptually, all purchase orders for the week are placed at the

beginning of the week and lead time is measured from this time. On receipt of the order, the components can be used in production only at the beginning of the next day and not on the same day. No carrying cost is charged for newly arrived components until beginning of the day following the receipt. It is possible for a purchase order to arrive during the same week in which it was placed.

3. Simulator assigns a unique order number to each production order it reads, which signifies the order as it progresses through its network of work stations. If all available queue positions are full at a particular work station, PROSIM V prints a message to this effect and that production order will not be processed. It will have to be placed again next week.

4. For each period of simulation the number of hours of operation for each work station are specified as "Time Available" and "Forced Overtime" values. These values must be specified in multiples of 5 to provide 5 equal daily periods to the simulator. In deciding how long to operate each work station, the decision-maker attempts to estimate the total time requirements for each work station. The work stations remain operable until the "Forced Overtime" time value, even if it goes idle due to lack of production orders. Each work station must operate for at least one full shift.

i.e. 40 hours/week; and it may operate upto a maximum of three full shifts during a period of five days. A "shift change cost" is charged whenever there is a shift change.

5. The user may change the "Hold Quantity" of any stock number - work station combination during any period. This provides him the flexibility in how he moves partial orders through sequential work stations. He may move each lot of the item, as it is manufactured, either to the next work station or he can accumulate several lots. It also provides him with a realistic mechanism for smoothing material flow and for achieving high utilization of equipment. All "Hold Quantities" are given in lot sizes.

6. PROSIM V simulates one day's production activities and then attempts to satisfy the generated daily demand for each finished goods. If stock on hand of a finished good is not sufficient to meet the demand, a back order for the item is generated. Back orders must be filled from production before the new daily demand is satisfied and before stock on hand can move above zero level. Backordered units and out of stock costs are calculated after all transactions (production, demand, receipts) for the day have occured.

7. Carrying cost for each stock number is computed daily. This is determined by multiplying 1/5 of weekly carrying cost with the stock-on-hand at the end of each day, after all transactions have occured. Daily carrying costs are then summed for the week.

8. The user may enter "Additional Sales" of any stock number during any period in the system. These sales are in addition to the regularly generated demand values. Additional sales are subtracted from stock-on-hand at the beginning of the week.

Since PROSIM V is basically designed as a teaching aid; the instructor can play a major role in controlling and influencing the environment in which the student's control system must perform. He can interject "noise" into the system at any time he wishes. Specifically, the following external disturbances can be interjected into the system.

1. Change in parameters in the demand generator for finished products. There are many types of changes which may be made (slope, period of cycle, variance, etc.).

2. Additional sales order may be placed for any stock number during the period. This is useful for emphasizing the importance of safety stock.

3. Change of mean and/or standard deviation of lead time generator. This emphasizes the need to keep running statistics on certain important variables in the system.

4. Change in any other parameter or cost in the system.

The simulator attempts to test the ability of the user's control system to respond to and adjust for external perturbations and other disturbing factors.

2.1.2.4 Cost Model

The basic objective of PROSIM V is to design a control system that will lead to decisions which, in the long run, will result in lowest total cost. A number of periods are simulated, by declaring decisions for the different periods in a single computer run. Simulator accumulates all costs resulting from sequential decisions. All pertinent costs are recorded during the simulation to provide guidelines on where excessive costs may be occuring. These costs are calculated for each simulation period as described below:

(a) DIRECT MANUFACTURING COST

(i) Labor (not idle) = sum of (Productive Regular Time Cost + Productive Overtime Cost + Set Up Cost) for all work stations.

(ii) Machine (not idle) = sum of (Productive Machine Cost + Set Up Cost) for all work stations.

(iii) Materials Used = sum of (Per Unit Cost x Number of Units Used) for all items. Per unit cost is recomputed each week for each stock number and is determined by the ratio A/B, where, A is the total cost of labour, machines, setups, materials, carrying, and ordering since the beginning of

the simulation, and B is the total number of units manufactured or purchased since the beginning of the simulation. Thus, per unit cost is a cumulative average.

(iv) Total Cost in a Period = (i) + (ii) + (iii)

(v) Total Cost to Date = Cumulative sum of (iv) over all periods.

(b) TOTAL MANUFACTURING COSTS

(vi) Total Labor = (i) + Idle Labour Cost.

(vii) Total Machine = (ii) + Idle Machine Costs.

(viii) Materials Used = same as (iii)

(ix) Overhead = Costant + (Factor of Variable Overhead) x (vi)

(x) Shift Change Cost = Number of Shift Changes x Cost per Change.

(xi) Total Cost in a Period = (vi) + (vii) + (viii) + (ix) + (x)

(xii) Total Cost to Date = Cumulative sum of (xi) over all periods.

(c) INVENTORY COSTS

(xiii) Order Cost = Sum of Purchase Order Costs.

(xiv) Carry Cost = Sum of Carrying Cost for all stock numbers.

(xv) Out of Stock Cost = Sum of Stock Out Costs.

(xvi) Total Cost in a Period = (xiii) + (xiv) + (xv)

(xvii) Total Cost to Date = Cumulative sum of (xvi) over all periods.

For each simulation period, the simulator summarizes all relevant and accumulated costs in the form of "Cost Summary Report". This report is useful for the PROSIM V instructor to evaluate the performance of the user's control system.

COST SUMMARY REPORT

(xviii) Total Plant Cost in a Period = (xi) + (xvi)

(xix) Total Plant Cost to Date = Cumulative sum of (xviii) over all periods.

(xx) Value of Materials Received in a Period = Value of all purchased items received in a period.

(xxi) Current Total Value of Inventory = The monetary value of the current inventory for all stock numbers.

(xxii) Penalty and External Costs in a Period = The sum of all penalties and other costs incurred external to the simulator. In each period the user can impose penalties and other external costs. A penalty parameter for excess inventory when multiplied by the difference between current value of inventory and maximum allowable inventory (parameter) gives the inventory penalty.

(xxiii) Total Penalty and External Costs to Date = Cumulative sum of (xxii) over all periods.

(xxiv) Total Score to Date = (xix) + (xxiii). By this figure the performance of the control system is judged.

PROSIM V is not particular about the accuracy of estimation of cost - terms. However, the measure of cost values should be consistentfor various cost - terms. Therefore, it is sufficient to have proportional values for cost parameters rather than actual ones. The values of various cost parameters should be such that they cause the

cost model to be responsive to "good" system designs. Determining a good balance of the costs involved in a particular problem is largely a matter of "cut and try".

2.1.2.5 Simulation Evaluation

The user receives feedback in PROSIM V in the form of a set of reports for each simulation period, identified and described as below :

(a) Results of Forecast - This report compares the forecasted demand to the actual demand on a weekly and cumulative basis.

(b) Status of Production System - This report shows the production orders waiting to be processed at each work station at the end of the simulation.

(c) Idle Time - This report shows the amount and cost of idle time at each work station.

(d) Inventory Status - This report shows all inventory transactions (receipts, issues, on order, back ordered, carrying cost, stock on hand, etc.) for each stock number.

(e) Total Manufacturing Costs - This report shows manufacturing costs for labour, machines, materials, overhead, and shift changes.

(f) Cost Summary Report - This report summarizes all costs for the period and the cumulative costs for the simulation run.

The user uses the above information to make any necessary adjustments to the parameters of his control system. He then makes a

new set of decisions and the entire process is repeated, until the reports show a fairly stable control system, i.e., how well it reacts to disturbances.

PROSIM V has been successfully used by Mize, et. al. (3) and others as a very effective teaching aid. They have provided the initialization data for various problems like the Shirt Problem, Bicycle Problem, Wooden - Case Problem, Transistor Radio Problem, etc. (19); to enable the user to test his own decisions for these systems.

As compared to the earlier PROSIM model of Greenlaw and Hottenstein (7), the later model - PROSIM V of Mize, et. al. (3), is much more flexible and realistic. Though, PROSIM covers a wider area of a production system than that of PROSIM V, it requires the decision maker to make a large number of inter-related complex decisions and requires a number of calculations to be made. In PROSIM V many subobjectives of PROSIM like Quality Control, Machine Operator Proficiency, Plant Maintenance, etc., are overlooked. But it applies better mathematical techniques to the limited field. It requires the user to make very few decisions and calculations as compared to PROSIM. These two are found to be very effective teaching aids in production management, due to the following advantages over the traditional approaches :

1. The design of a control system is emphasized.
2. They force the decision maker to consider the dynamic nature of the production environment.

3. They provide a conceptual understanding of the total operations control system and of the interactions among system concepts.

4. They foster an appreciation of the concepts of feedback, corrective action and integrated information systems.

2.2 Simulation Applications To Real Life Production Systems

So far, very few efforts have been made to apply computer simulation in real life production systems. Le Grande (20) developed a partial simulation model for very short-term corrective action using actual operating data. As was pointed out earlier, most of the work has been directed towards applying educational simulators to real life situations. Fey (9) applied DYNAMO - a simulation language for continuous system, to the customer-producer-employment model of a manufacturer of high-quality electronic components. The development of the model and results are extensively discussed by Forrester (6).

The results obtained by using DYNAMO are quite useful for the manager to stabilize employment levels, factory backlogs and cash requirements. However, it only provides him with the overall guidelines to make such decisions. On the contrary the PROSIM simulators help the manager to make both short-term and long-term decisions. PROSIM V is ideal for teaching and research purposes. The simulator provides the user with the detailed analysis of his production system for the day - to - day planning under situations when he is faced with wide range of decision alternatives to choose from.

Despite the powerful capabilities of the educational simulators, heretofore little effort has been put to make use of this methodology, to solve industrial problems, both in India and abroad. This can be attributed to the following reasons :

1. Cost of carrying out simulation experiments is generally prohibitive.

2. Most of the modern production systems are highly complex in nature. There is multiplicity of highly sophisticated transfer functions in the system which restrict the design of integrated production planning and control system. The term transfer function is used here in a broader sense to represent all decision processes, mathematical or otherwise.

3. Lack of accurate and timely information. In majority of industries, the relevant data is not available in the required form, specially the past data and various standards of performance e.g. processing and setup times, inventory costs, etc.

4. Uncertainty prevails in most of the industries. Ignorance is a virtue in such industries. Many a times, decisions made - have immediate repercussions. This again is attributed to the lack of proper data and improper management information systems.

5. The speed and the size of computers put a restriction on the size of the problem that can be handled in computer simulation. Sometimes non-availability of high-speed and large-size computers becomes a big hurdle in implementing the computer simulation techniques.

Currently, the computer facilities available in this country is inadequate to cope up with the demand of the industries. Only a limited number of Indian industries are able to use simulators for the design of their control systems, firstly because of very few numbers of 'Computer Centres' all over the country and secondly because of the improper utilization of the existing facilities. But this difficulty, faced by the Indian industries, is expected to be removed very soon if the rate of growth of Computer Technology is kept at a more accelerated pace than at present.

In the presented work an effort has been made to improve upon the capabilities of PROSIM V, so that one can handle real life industrial problems. The model of Mize, et. al. (3) has been considerably modified and new features have been added. The effectiveness of the simulator can be best judged, by comparing the results of the simulation with those of real life production system. The data, from J.K. Electronics for the manufacture of TV Sets, was gathered to check the validity of the modified PROSIM V simulator. The model has been developed keeping, the situations in mind which

are more consistent with the Indian environment. It should at best satisfy the requirements of a typical Indian production manager, who may get entangled with several production management problems of varied nature due to limited theoretical background. This simulator holds a great promise in future, specially for Indian industries, due to its obvious advantages and because of its wide applicability in the fields concerned.

CHAPTER III

DEVELOPMENT OF A MODIFIED PROSIM V SIMULATOR

PROSIM V simulator as developed by Mize et. al. (3) can not be used in its present form, for a real life production situation. This is so due to the following reasons :

1. PROSIM V was primarily developed as an educational tool. The simulator serves more like a "tester" for the evaluation of the user's decisions, then to aid the user to arrive at those decisions to control the production system.

2. It does not incorporate some of the very important features of the production systems e.g., sales forecast, real estimates of variables and parameters for inventory control, etc.

In order to account for some of the above-mentioned limitations, PROSIM V has been modified considerably in the present research. The modified simulator is referred hereafter as "MOD - PROSIM V". The modifications incorporated in the simulator can be broadly categorized as follows :

1. A general purpose model has been developed to forecast the sales of finished goods depending on the past demand history of the particular product.

2. The inventory control model used in MOD-PROSIM V incorporates features for determination of the values of pertinent inventory parameters for each purchased item e.g., part requirements of the finished good, economic and discount order quantities of

the purchased items, etc. These parameters are important, to arrive at an optimum inventory decision policy.

3. For effective production planning, a decision policy has been formulated for generating production orders for each manufactured item during each simulated period.

Above mentioned modifications have been explained in details in the following sections. To suit the Indian environment, MOD-PROSIM V takes into account the six working days a week. While in the original model of Mize et. al. (3), it was assumed that the production system works for five days a week, as explained in Chapter II.

3.1 Development of a Generalized Forecaster Model

The simulator determines the forecasted demand for each finished good using a time series model, which is capable of generating demand trends having a wide variety of slopes, growth rates, cycles and variations. A time series can generally be considered to consist of a random component, an arbitrary component such as catastrophic events and non-random components that include trend, cyclicity and persistence. The term random component refers to the pure random component of the process. This component is generally very difficult to assess and is usually neglected in stable systems. The arbitrary or catastrophic events are rare events about which no prediction can be made because of lack of data and their

arbitrary behaviour. The non-random component may itself be composed of trend and cyclicity which is a function of time alone; and persistence which defines the sequential dependence of the time series.

The time series used in the model for generating the forecasted demand for each finished product is represented by the following mathematical relationship :

$$W(t) = A + Bt + Ct^2 + D(\cos(\pi t/E)) + F(\cos(\pi t/G)) + H(\cos(\pi t/U) + DEV \qquad (3.1)$$

where

$W(t)$ = generated demand of the finished product for the time period "t", in units,

A = the beginning constant or "Y" axis intercept,

B = coefficient of "straight line" slope,

C = coefficient of quadratic growth term,

D, F, H = coefficients which determine the amplitudes of first, second and third cyclic trends respectively,

E, G, U = coefficients which determine the periods of first, second and third cyclic trends respectively,

DEV = a randomly chosen deviate from a normal population having a mean of zero and a standard deviation of AK. This normal distribution is truncated at three standard deviations below and above the mean.

This forecaster generates the demand for each period assuming a linear-quadratic growth. As many as three types of cycles can be imposed on a single demand trend. The arbitrary component of the time series is represented by the variable DEV, the value of which is calculated by using Monte Carlo Simulation technique (21). This keeps the usual off-control points in the frequency analysis of the demand pattern at the confidence level of 99.73% by using the control limits of three standard deviations. Using this model a value for each parameter (A, B, C ..... etc.) can be calculated for each finished good. The demand trends for the several finished goods can be widely different. As explained in Chapter VI, regression analysis is used for the estimation of the coefficients (A, B, C ..... etc.), as sufficient past demand data are available.

3.1.1 Regression Analysis

Regression analysis deals with the determination of the causal relationship between the exogenous and indogenous variables. The demand coefficients of regression equation are generally estimated by the method of least squares (22). To calculate the values of the demand parameters, the values of the frequencies of period cycles must be known. To estimate the values of coefficients E, G and U; iterative procedure and "Correlation and Spectral Analysis" techniques are used. The techniques are discussed in the later sections of this chapter. Once the periods of the cycles are identified, the values of other coefficients is calculated in a manner given below :

1. The variables $W(t)$ and t are redefined, to reduce the computational efforts, as follows :

$$\left.\begin{aligned} K(t) &= W(t) - \overline{W} \\ \text{and} \quad h &= t - n/2 \end{aligned}\right\} \qquad (3.2)$$

where

n = number of available past demand data

$\overline{W}$ = average of past demands over last n periods.

2. Values of the coefficients in equation (3.1) after above substitution of Step 1, is determined by solving the determinant having elements in first row as $K(t)$, 1, h, h^2, Cos (π t/E), Cos (π t/G) and Cos (π t/U). These are the multiplicants of coefficients (A, B, C .... etc.) in equation (3.1). The elements in other rows of the determinant are calculated by summing the product of first row elements with the first row element of the particular column over all the past n periods. To find the value of ith element of jth row of the determinant, summation should be taken of product of ith and jth elements of first row. For example, the value of 4th element in the 6th row is given by $- \sum_n h^2$ Cos (πt/G). The order of this determinant is 7, as the number of degrees of freedom of the demand variable is 6.

3. The value of this determinant is set equal to zero. The elemental determinants of this determinant are of the order 6. The values of these elemental determinants - B1, C1, D1, E1, F1, O1, and F2; are calculated by employing Pivotal Condensation Method (23).

By setting the value of the determinant equal to zero, the following equation is obtained:

$$K(t) \times B1 - C1 + h \times D1 - h^2 \times E1 + \mathrm{Cos}\ (\pi t/E) \times F1$$
$$- \mathrm{Cos}\ (\pi t/G) \times O1 + \mathrm{Cos}\ (\pi t/U) \times F2 = 0 \qquad (3.3)$$

Substituting the values of K(t) and h from equation (3.2) into equation (3.3) and comparing the coefficients of equation (3.1), the values of the demand parameters are obtained as follows :

$$\left.\begin{aligned} A &= (C1 + D1 \times n/2 + E1 \times (n/2)^2) / B1 + \overline{W}, \\ B &= (- D1 - E1 \times n) / B1, \\ C &= E1/B1, \qquad D = - F1/B1, \\ F &= O1/B1, \qquad H = - F2/B1 . \end{aligned}\right\} \qquad (3.4)$$

4. The value of AK, standard deviation of demand, is calculated from the past data using the equation :

$$AK = \sqrt{\frac{\sum_{n} (\text{Error in forecast})^2}{n - f}}, \quad \text{when } n > f \qquad (3.5)$$

where,

f = degrees of freedom (6 in this case)

and Error in forecast = difference between actual and forecasted demand.

To use the above mentioned method a minimum of 7 periods demand history must be known because the degrees of freedom is 6. The accuracy in the estimation of the demand parameters improves with the increase in the amount of past data available for their estimation.

3.1.2 Determination of Periodicity in the Cycles

Twice the values of coefficients E, G and U in equation (3.1) represent the periodicity in the three cycles which are present in the time series. To estimate the frequencies of the cycles, the following procedure is followed :

1. The optimum values of E, G and U are estimated for the minimum total absolute error in forecasting in the past n periods. The demand variable in equation (3.1) is assumed to be represented by a discrete time series, hence the periods of cycles are integers. This is true in many real life situations. By employing an iterative procedure the various values of E, G and U are examined for getting the minimum value of the total absolute forecasting error for past n periods. The values of coefficients E, G and U are varied in the steps of 1/2 in the range from 1 to n/2. This is done because the periodicity of cycles have integer values and the minimum possible number of periods in a cycle is 2. This method is useful specially when the value of n is not very large. The number of iterations increases considerably with the increase in the number of past demand periods.

2. The calculated values of E, G and U are checked by correlation and spectral analysis. The presence of periodic cycles in the time series is indicated by the periodicity in the correlogram and spikes at appropriate frequencies in the spectral density function. These techniques have been used to calculate the

approximate values of E, G and U for very large values of past data situations when the iterative schemes are very difficult to use. Once the approximate values are known, the exact values in their neighbourhood are found by iterative method as discussed above. The details about correlation and spectral analysis techniques are given in Appendix A.

Depending on the type of product, the time series can be easily modified to take into account different types of trends and periodic components. A trend represents the long - term variation of a process. A plot of past data indicates whether a trend is present and if so, whether it can be expressed as a linear, polynomial or exponential function of time. The actual nature of the trend may be difficult to identify because of the presence of cyclic and random components. To eliminate these random components, the method of moving averages (1) is used. When n values of past data is available the maximum possible number of periodic components in a time series is n/2. Generally a much smaller number of significant harmonics are considered. The techniques of correlation and spectral analysis are used, when the exact number of cycles for any product are not known.

Since the time series of demand variable of any product may change with time, necessary corrective action has been taken after each demand period to modify the forecaster model. During each period the forecasted demand is compared with the actual demand to evaluate the effectiveness of the forecaster.

3.2 Inventory Control System

The purpose of the inventory planning and control function is to determine the appropriate inventory policies with a view to keep the various costs associated with the inventories at a minimum. The most common classification of inventories is - (i) raw materials and purchased parts, (ii) in-process inventories and (iii) finished goods. For each purchased item the decision is to be made about how much to order at a time and when (or how often) to place an order.

In MOD-PROSIM V the purchase orders are generated for the raw materials required for the production of finished products during the simulated period. The order quantity of each purchased item is determined from the forecasted demand of the finished goods during that period. The purchase orders for each raw material are accumulated in the simulator, over the simulation run, till the Cumulative Order Quantity (COQ) of the particular item reaches the value of its Economic Order Quantity (EOQ). EOQ of any purchased item is the optimal ordering lot size of the item which minimizes the total inventory costs associated with the item. During the simulation period if the EOQ of any purchased item is exceeded by its COQ a purchase order equal to COQ is placed.

In the above stated inventory policy it is assumed that - (i) sufficient safety stocks for use during the variable lead times are maintained and (ii) the forecasted demand during the lead time does not vary much i.e., there are no unexpected fluctuations in

the demand trends. These assumptions are valid for most of the production systems.

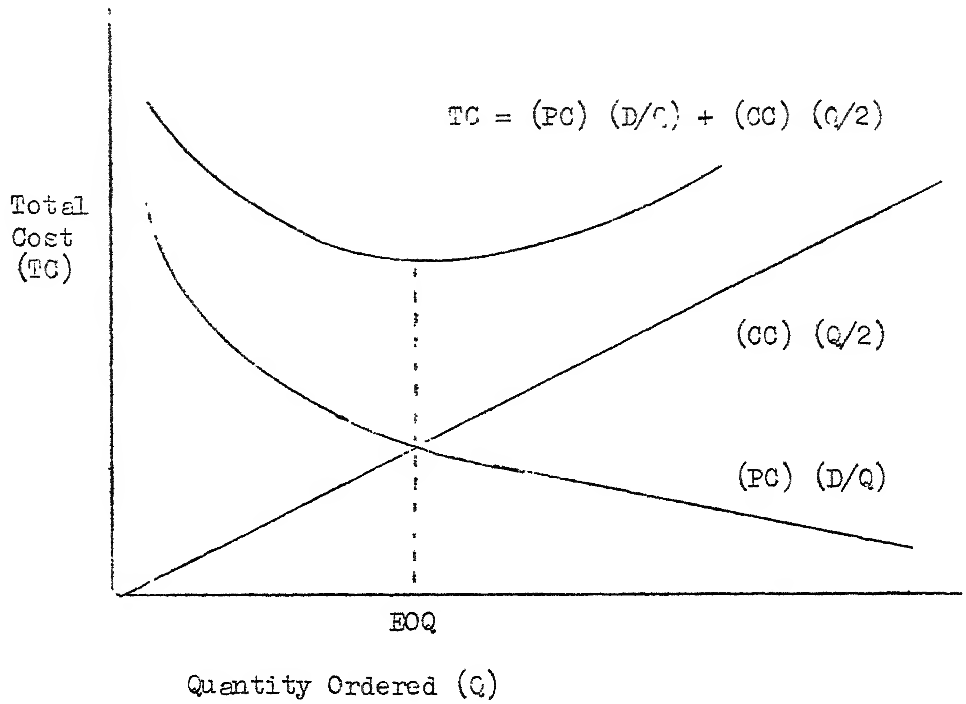


FIGURE 5

TOTAL COST FUNCTION FOR CLASSICAL INVENTORY MODEL

To implement this inventory policy the value of EOQ for each purchased item must be precisely known. The effect of order quantities on the various costs is represented graphically in Figure 5. The EOQ for each item is determined by using the Classical Inventory Model. The economic order quantity can be calculated using the following relationship :

$$ECQ = \sqrt{\frac{2\ (PC)\ (D)}{CC}} \quad \text{units} \tag{3.6}$$

where

PC = procurement cost of each order.

CC = carrying cost per unit per time period.

and D = maximum possible usage rate of the item per time period.

The values of parameters PC and CC for each purchased part are known for the production system to be simulated. MOD PROSIM V computes the values of D for each purchased item by multiplying the parts requirements for each unit of the finished goods (R) with the Estimated Plant Capacity (EPC). The value of EPC for each finished product is calculated by dividing the total available time per simulation period by the cycle time or the longest process time of the item. The total requirements of purchased items for each finished item (R) must be known precisely to the simulator. This is easily done by making a few calculations for a small problem. But, this procedure tends to be too clumsy for larger problems involving a large number of parts and sub-assemblies. In the literature the problem of the determination of total parts is referred as the "Explosion Problem". Very many techniques based upon the matrix algebra have been reported in the literature. MOD-PROSIM V employs the algorithm of "Plug and Chug method" for the explosion problem. This is a much more simplified technique as has been explained in details in Appendix B.

For each purchased item the value of EOQ is calculated by using the equation (3.6). In real production systems a raw material supplier often offers a quantity discount when orders larger than an order size are placed. MOD-PROSIM V takes this feature into account by assuming that only one discount price for each material is provided by the supplier. This discount price is applicable only for certain order size called "Discount Order Quantity (DOQ)". The value of DOQ for each item is computed by multiplying a "Factor of Discount Order Quantity (FDOQ)" with the corresponding value of EOQ. The value of FDOQ is assumed to be same for all the purchased items.

Another important variable used in the inventory control system is the "lead time" of each purchase order. As explained in Chapter II, MOD-PROSIM V generates the value of lead time using Monte Carlo Simulation.

3.3 Operations Planning

MOD - PROSIM V incorporates all the above mentioned features to structure a decision policy for raw materials inventory. As explained in Chapter II the in-process inventory is governed by the hold quantities at each work station. To control the finished goods inventory a decision policy is formulated for the production planning of all assemblies and sub-assemblies. This requires the generation of production order for all the items manufactured during each of the simulated period. Weekly production orders are generated from the forecasted demand for each

finished product. This assumes that the production orders placed in a week satisfy the weekly demand of the finished products. Further, it is assumed that the forecasted demand is a good estimate of the actual demand and the planned production can be achieved in most of the simulation periods.

Most of the assumptions made in MCD-PROSIM V hold good for real production systems. The simulator reduces the load of the production manager considerably and provides him with a decision policy which he can follow on a long term basis.

CHAPTER IV

COMPUTER PROGRAM DETAILS

Two separate packages of computer programs written in FORTRAN IV have been developed for MOD-PROSIM V. These two are complementary to each other in use and solve the mathematical models proposed in earlier chapters. One of the programs is for the forecaster model. It estimates the various demand coefficients for the simulator. The other program is the simulator itself. It uses the output of the earlier program as the initialization data. The two programs are kept independent of each other for use because this simplifies the handling of the data and reduces the memory storage requirements of the computer. The details of data requirements of data collection are given in Chapter V. The FORTRAN listings of these programs have been included in the Appendix C. Listings contain a generous number of COMMENT Cards to assist the user in following the detailed logic. A list of various parameters and variables used in the program is also included in the listing of each program.

4.1 Forecaster Program

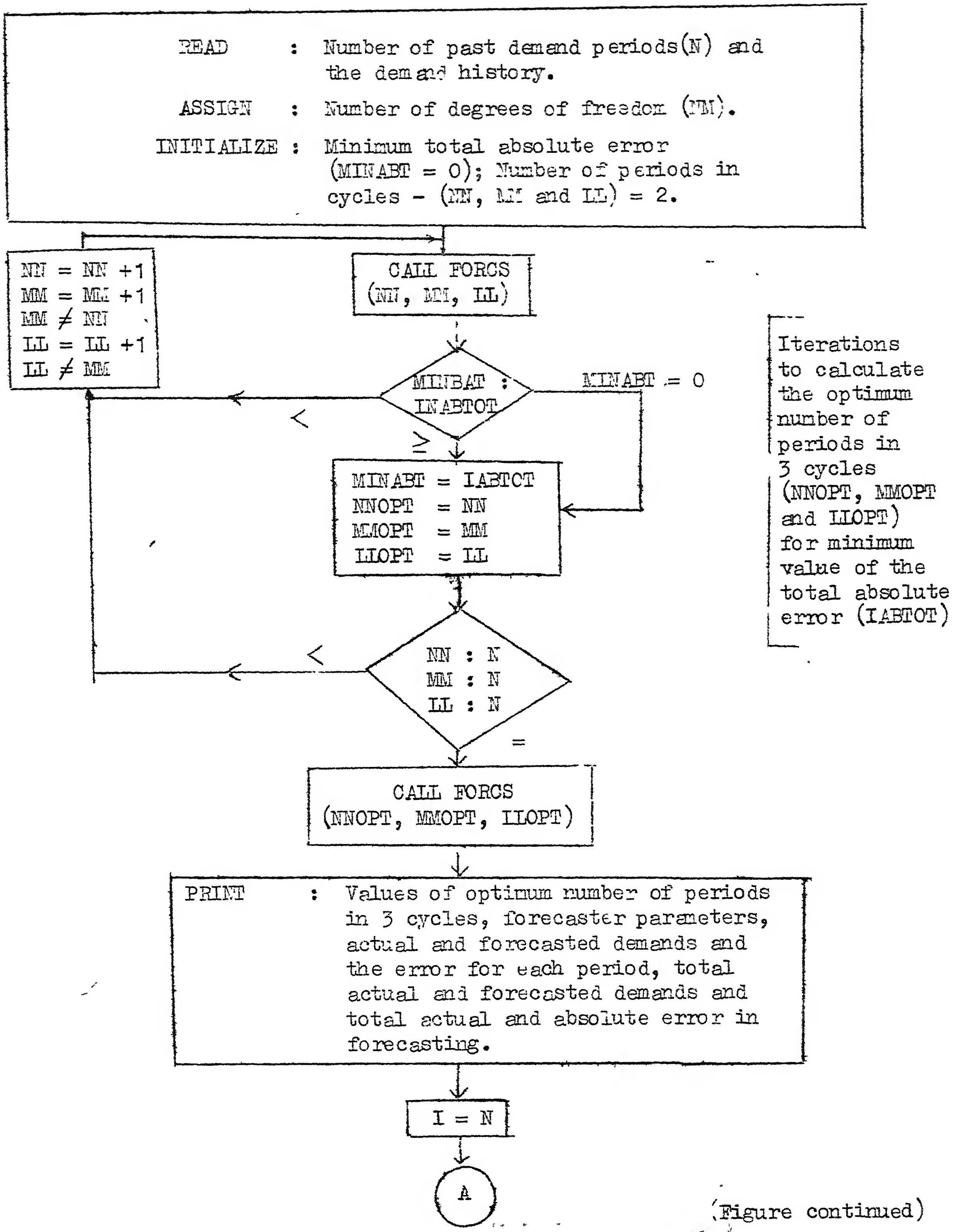
This program has been developed for the generalized forecaster model. It estimates the values of forecaster parameters for the finished good, as was explained in the previous chapter. The package is used independently for each of the final products. It provides optimum values of the parameters in the form of printed reports and punched cards. The punched cards are used directly as

simulator initialization data input. The size of the problem that the program can handle is defined by the number of available past demand data. The program has been designed for a maximum of 100 past demand periods, but this restriction can be relaxed by modifying the DIMENSION statements.

For 25 past demand data, the iterative procedure requires 127 seconds of computer time on IBM 7044 system. But, when the frequency of each demand cycle is precisely known the computation time is reduced considerably. For example, the same problem took only 6 seconds when the demand cycle was precisely known. The program contains one MAIN program and one subroutine FORCS, which is called from the MAIN program for each iteration. The gross logic of these programs is explained in Figure 6 and Figure 7.

4.2 Simulator Program

The computer package consists of approximately 1200 statements in FORTRAN IV. A complete report of the results is printed for each week of simulation. Two sets of punched outputs are obtained during the simulation run. These punched cards are used as input data for further simulation runs. The simulator consists of a MAIN program and seven subroutines. The functions of each of them are explained in the following sections. The general logic incorporated into the simulator is given in Figures 8 to 12.



(Figure continued)

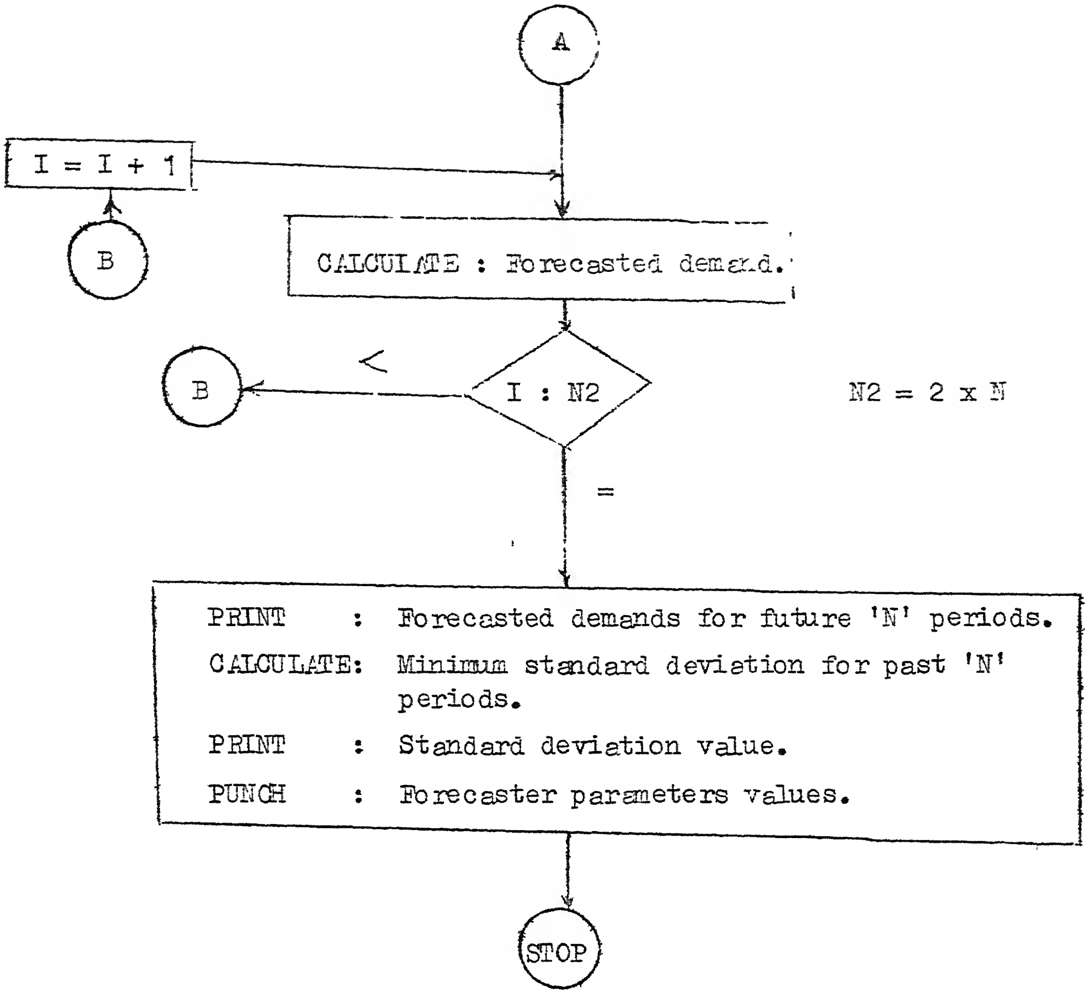
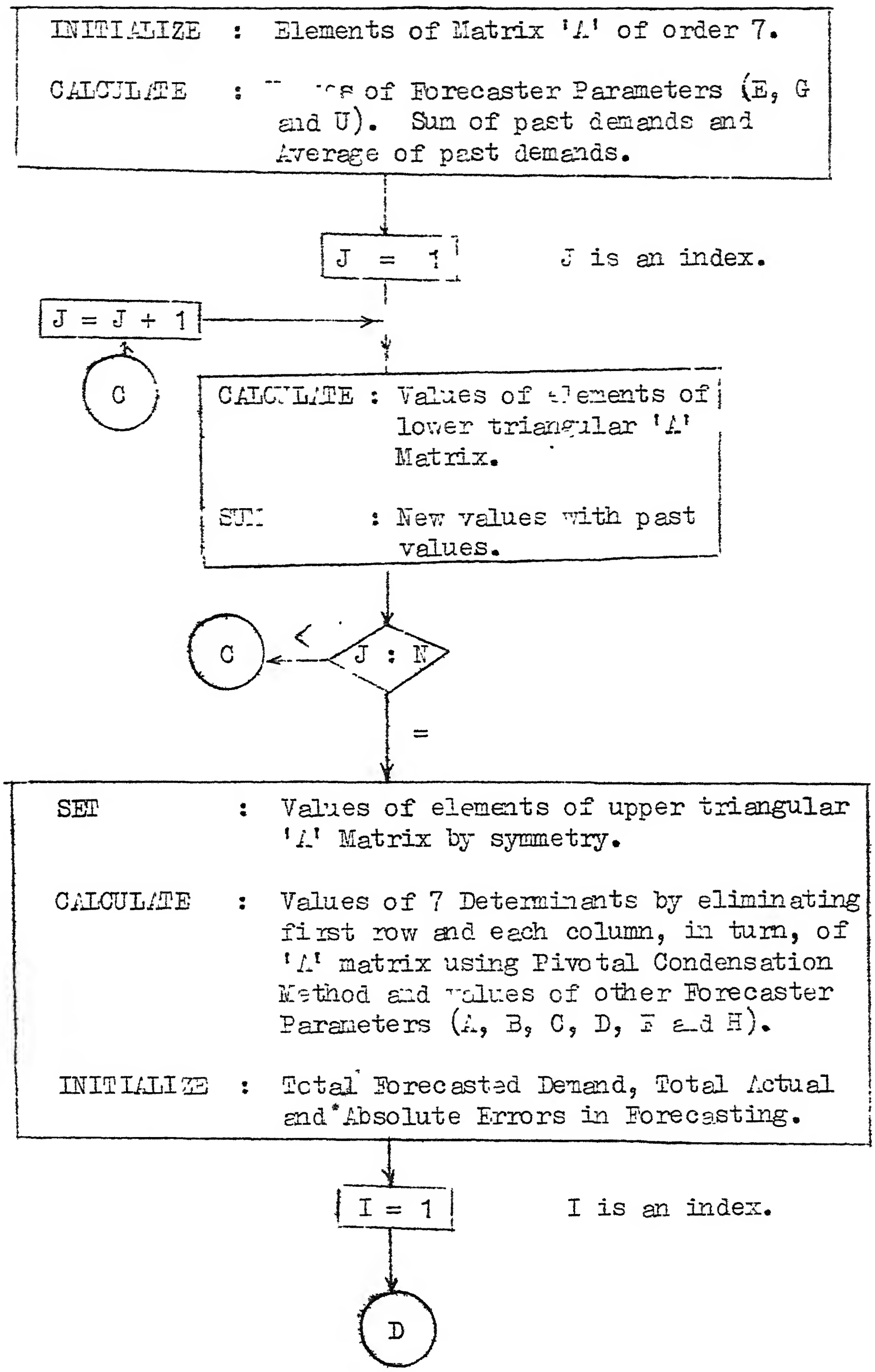


FIGURE 6

FLOW DIAGRAM OF MAIN PROGRAM OF THE FORECASTER.



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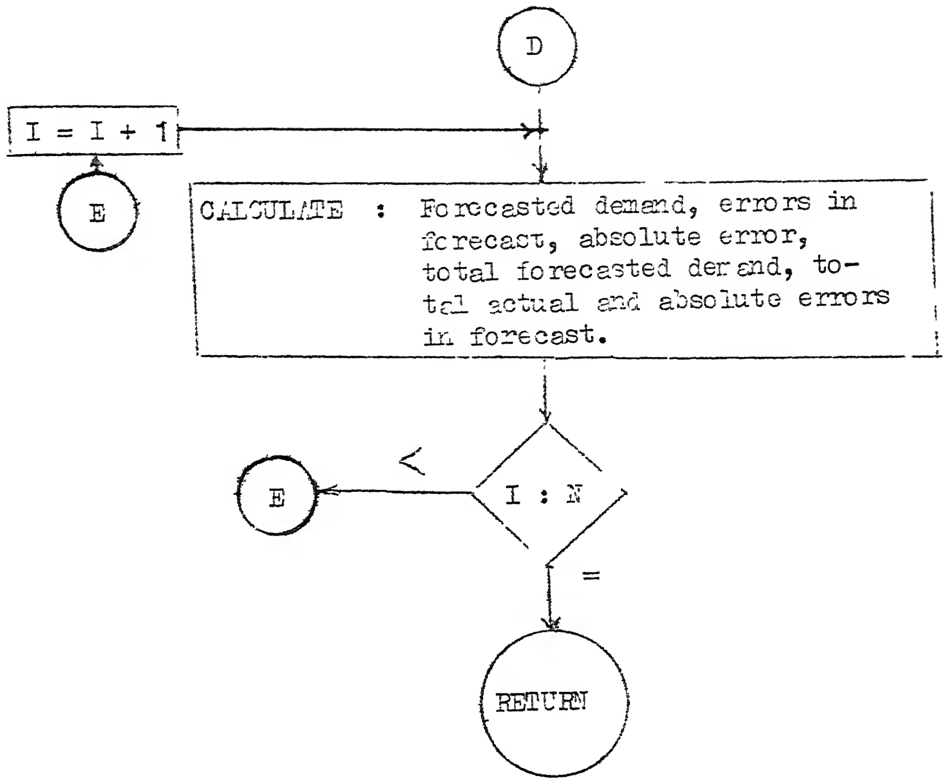
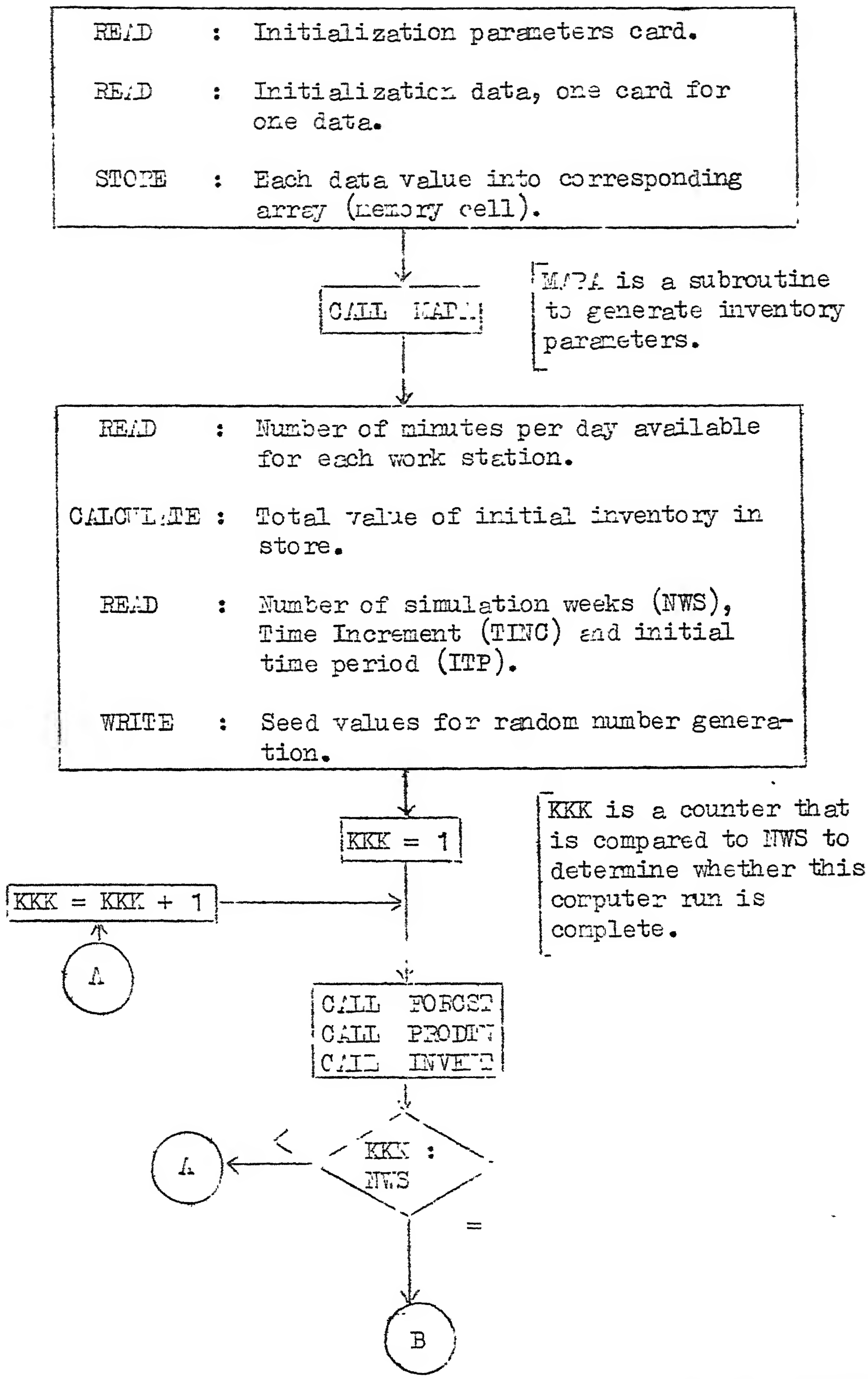


FIGURE 7

FLOW DIAGRAM FOR SUBROUTINE FORCS OF THE FORECASTER



(Figure continued)

B

PUNCH	:	Production status values for work stations; stock on hand and stock on order for each stock number.
WRITE	:	"SIMULATION COMPLETED".
READ	:	Actual unit cost and actual inventory cost.
WRITE	:	Table of summary of results (SUMRY).
READ	:	Plot characters (PLT) for 5 plots.
CALCULATE	:	Scaled values of SUMRY for 5 plots = T $(0 < T < 50)$.
WRITE	:	Values of 'T' on time scale for 5 plots.

STOP

FIGURE 8

FLOW DIAGRAM FOR MAIN PROGRAM OF THE SIMULATOR

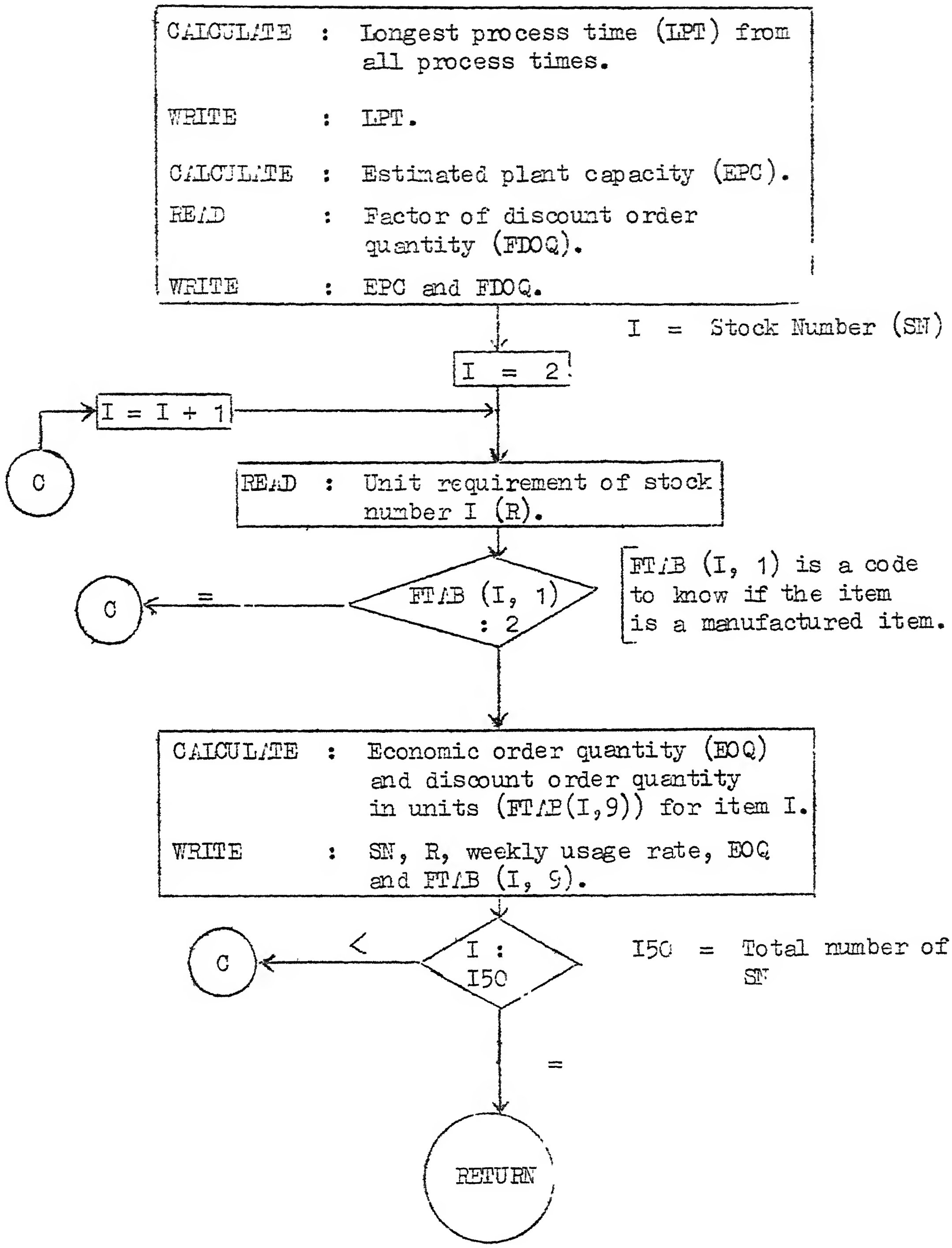


FIGURE 9

FLOW DIAGRAM FOR SUBROUTINE MAPA OF THE SIMULATOR

READ : Forecasts (actual sales data).

GENERATE : Actual demands for this period.

COMPARE : Forecasts to actual.

WRITE : Results of forecasts.

CALCULATE : Purchase orders required for raw materials in this period.

GENERATE : Random lead time for each purchase order.

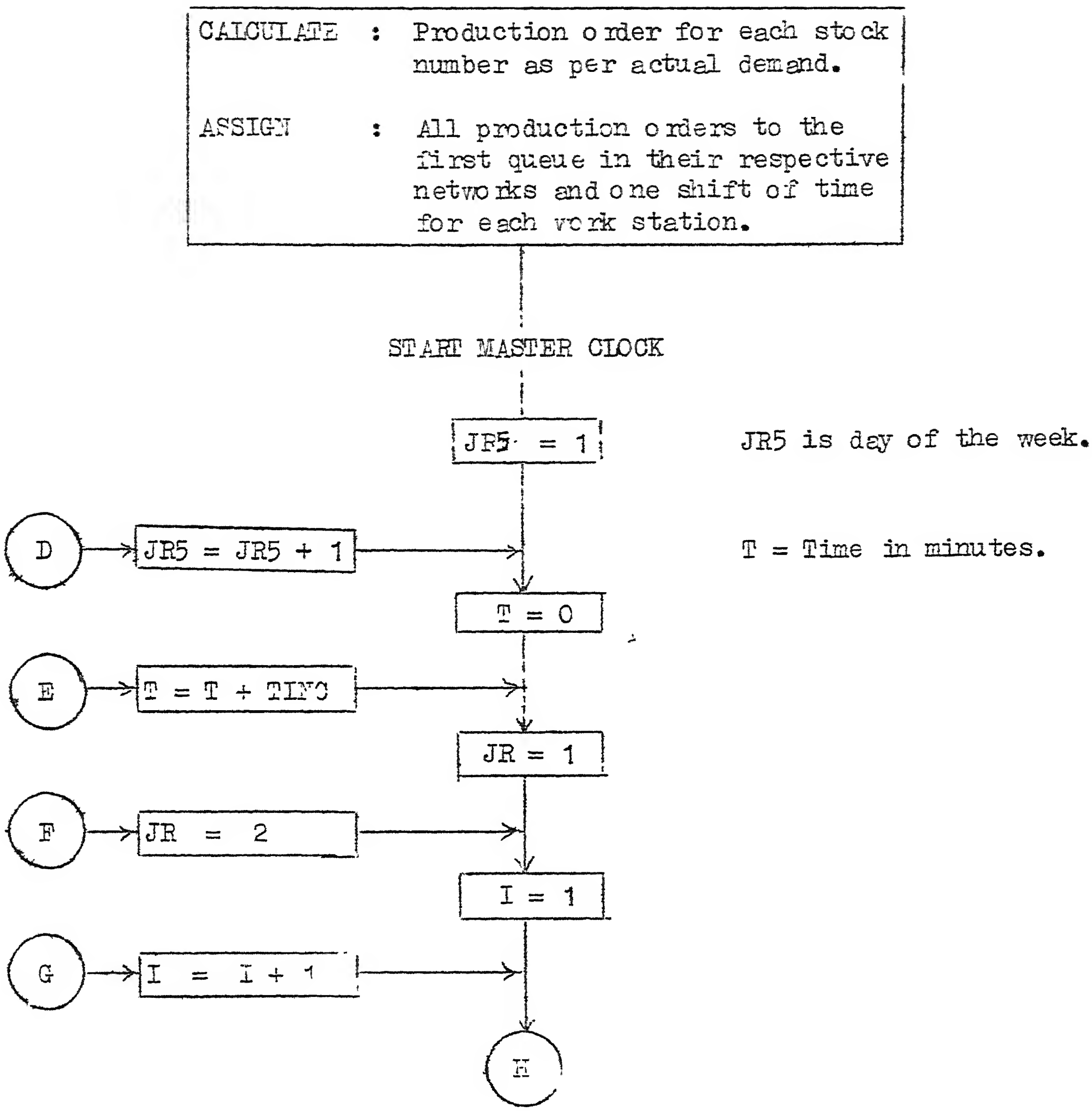
CALCULATE : Day of arrival of each purchase order.

WRITE : Purchase order number, stock number and order size for each item.

RETURN

FIGURE 10

FLOW DIAGRAM FOR SUBROUTINE FORCST OF THE SIMULATOR



(Figure continued)

H

Simulates one TIME of operation for Work Station I.

Depending upon the set of conditions at time T, simulator will perform one or more of the following functions on Work Station (W.S.) I :

- Continue processing the lot now on the W.S.
- Move the lot to the 'Hold Block', if processing is complete.
- Move the 'Hold Quantity' in the 'Hold Block' to the first available 'Queue' position at the following W.S.; <u>or</u>, move the 'Hold Quantity' to inventory (which increases stock on hand) if W.S.I is last on the network.
- If 'Queue Position' 1 is empty, the 'Queue' is indexed; i.e., all orders in the 'Queue' are moved up one position.
- If there are no orders in the 'Queue', the machine is idled.
- If an order is in 'Queue Position' 1, stock on hand of all items added at W.S.I is checked to be sure, sufficient quantities exist to produce one lot.
- If insufficient materials exist, the 'Queue' is searched for an order that can be produced. This order is moved to 'Queue Position' 1.
- Whenever there is an order in 'Queue Position' 1 for which sufficient materials exist, one lot is moved to the W.S. Set-up time, if any, is calculated. Processing time is determined. This determines the time when the lot will be finished.
- Various costs are accumulated.
- Inventory levels are updated.
- Idle time (if any) is recorded.
- Number of set-ups are recorded.

P

(Figure continued)

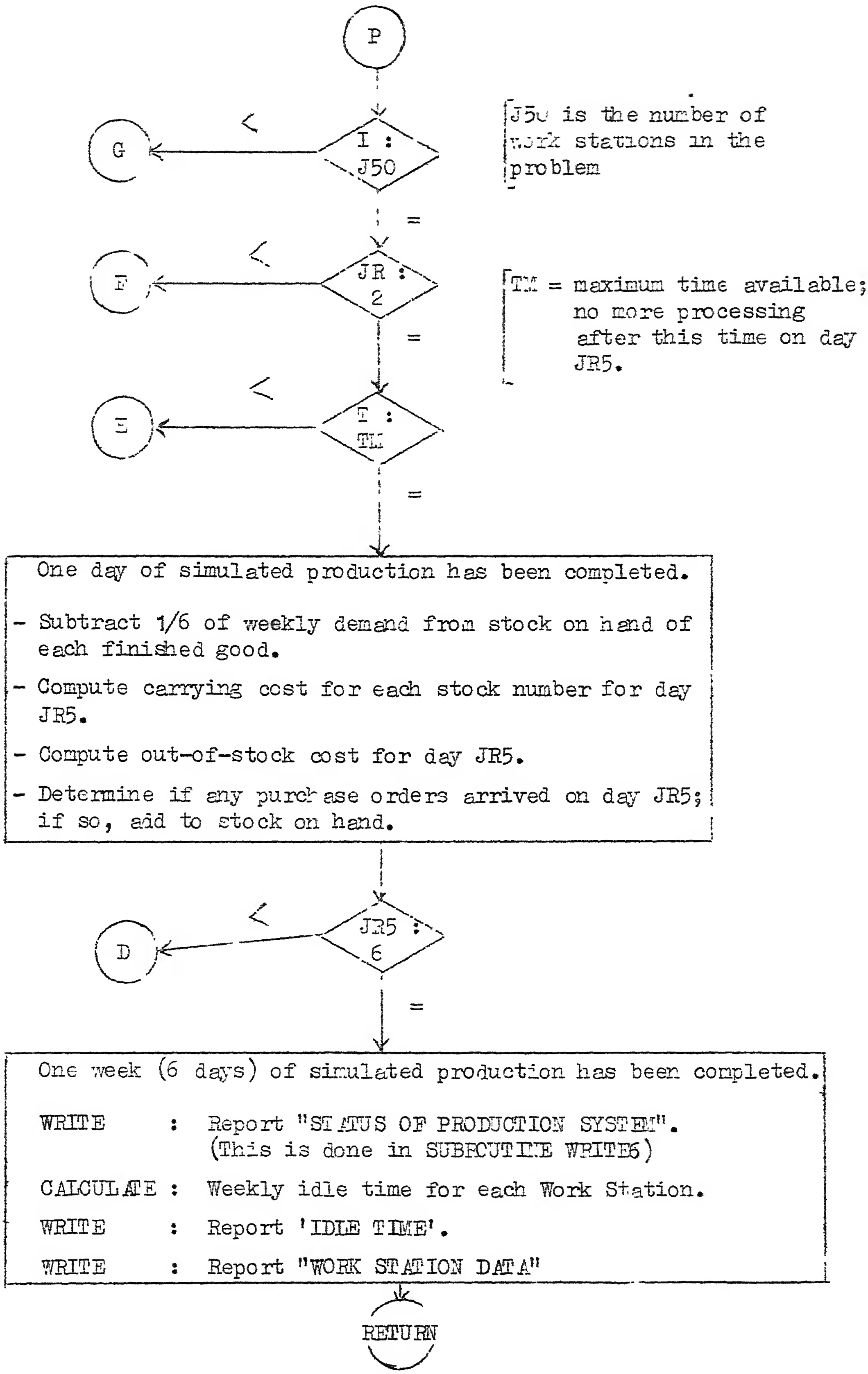


FIGURE 11
FLOW DIAGRAM FOR SUBROUTINE PRODTN OF THE SIMULATOR

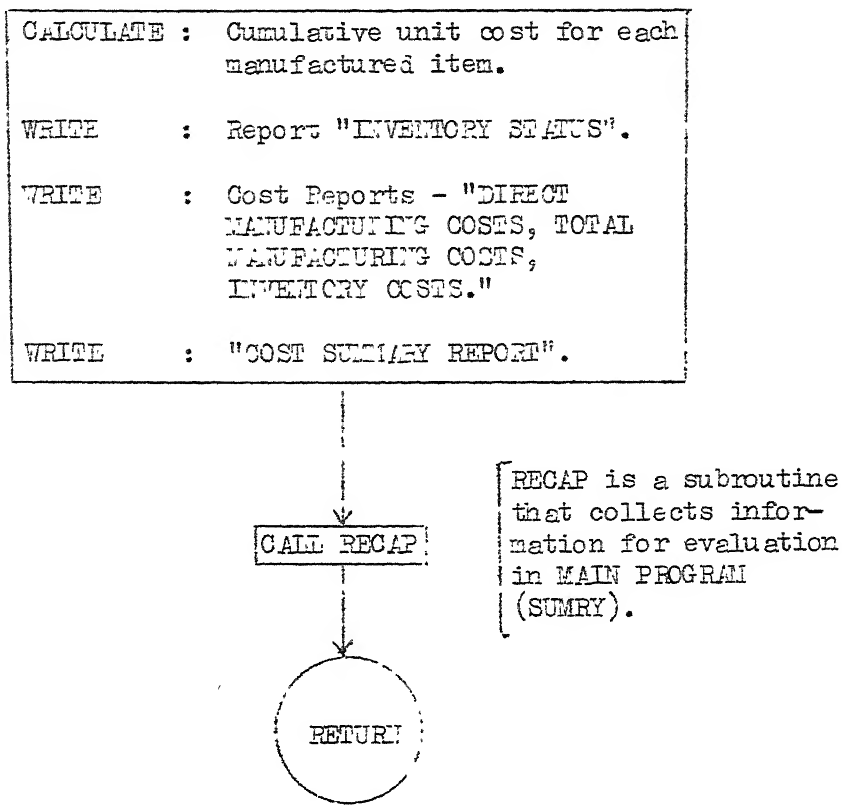


FIGURE 12

FLOW DIAGRAM FOR SUBROUTINE INVENT OF THE SIMULATOR

4.2.1 MAIN Program

This program consists of three parts. The first part is used to create the data set for the initialization of the simulator. It also calls the subroutine MAPA to generate the inventory parameters. The second part calls the subroutines FCRCST, PRODTN and INVENT during each period of simulation. The third part of the program prints tables and plots charts for the results of the simulation run. It is used after the simulation has been carried out for the desired number of periods. The relationship between pertinent variables is plotted for each of the finished products. The plot scales can be suitably modified to meet the individuals requirements.

4.2.2 Subroutine Programs

Mainly three subroutines govern the simulation of the production system for each simulated period. These are identified as FORCST, PRODTN and INVENT. Subroutine FORCST computes the forecasted demand for finished products. It also generates the lead time for each purchase order. Subroutine PRODTN generates the production orders for the manufactured parts. It uses a "Master Clock" to simulate the production activities at each work station for each time increment. It also keeps the timely and cumulative record of the production times, the inventory status and the various costs involved in the production system. For each simulated period the subroutine WRITE6 prints intermediate and end-of-the-week status of the production system.

Subroutine INVENT calculates and prints the various weekly and cumulative costs. It calls the subroutine RECAP to store all important results obtained in the simulated period. These pertinent results are used at the end of the simulation run in the main program to print tables and to plot the graphs. Subroutine MAPA generates the inventory parameters for each purchase item, which are required in the simulator. As explained in Appendix B, the punched output of the "Explosion Program for unit requirements is used as the input data for MAPA. Subroutine RANNUM generates two random numbers for the given seed values, having normal distribution and values between zero and one. These random numbers are used in Monte Carlo sampling for generating demand and lead time distributions in the subroutine FORCST.

4.3 Capabilities of MOD-PROSIM V

MOD-PROSIM V has been basically developed for the IBM 7044 system. The size of the available computer memory puts a constraint on the capability of the simulator. MOD-PROSIM V is capable of handling a manufacturing system consisting of upto 15 work stations, 60 stock numbers and 3 finished goods. This requires about 100,000 bits of computer memory. To accommodate larger production systems the procedure of "cut and try" is employed, as explained in Chapter V.

The computer time required for each simulated period depends very much on the computational speed of the computer used.

It is also a function of the size of production system, the duration of the simulation run and the time increment used for simulation. The IBM 7044 system requires about 70 seconds to simulate the 15 x 60 x 3 problem (15 work stations, 60 stock numbers and 3 finished goods) and about 16 seconds for 7 x 20 x 1 problem. For both the problems the simulation run was 25 periods (weeks) with the time increment of one minute. The computer time can be reduced considerably by using a larger time increment. Maximum possible value of time increment is the largest common divisor of all lot processing times and the set-up times.

In addition to the printed reports of simulation results, MOD-PROSIM V also provides a deck of punched cards as output. One set of punched cards consists of the initial inventory status of the production system. Other set of punched output consists of stock-on-hand and stock-on-order for each purchased item for the last simulation period. These outputs can be used directly either in other computer programs or for further simulation run. In MOD-PROSIM V the computer run is administrated and the tape/disk systems are used in a way similar to that done by Mize et. al. (3).

CHAPTER 7

DATA REQUIREMENTS AND DATA COLLECTION

In order to simulate a production system on MOD-PROSIM V, it is necessary to structure a model for the production system under study. An extensive study of the production system is made by analyzing the various operations involved and the pertinent parameters.

Since MOD-PROSIM V is a general purpose simulator, many different types of production problems can be simulated on it. The major difficulty in problem formulation is faced while structuring the system's model suitable to the requirements of the simulator. The following restrictions are placed by the simulator on the problem representing a production system :

1. MOD-PROSIM V is restricted in its application to large complex systems due to the computer limitations. Hence the problem is structured using as few work stations and stock numbers as possible, without seriously affecting the characteristics of the production system under study. In case of large-size systems this is achieved by selecting an independent sub-system for which relevant data are available. If possible the purchased items are grouped together according to their functional use. All this results in a compact system - enabling easy analysis.

2. Any item carried in the inventory is assigned a unique stock number. Finished products are assigned numbers 1, 2, 3, — n, where n is the total number of finished products. All other items can

be numbered in any desired order, starting with n + 1. No discontinuity in numbering is permissible.

3. Items requiring processing must have an operations network. The network may consist of one or more work stations. Multiple processing of any item at the same work station is not permissible to avoid the looping.

4. There is a limitation on the number of components in any sub-assembly. In MOD-PROSIM V this parameter is specified as J50. The maximum value attributable to J40 is 5. In the operations network of a processed item, the full amount of any component required must enter at one and only one work station.

5. "Dummy assemblies" are incorporated to account for situations where an assembly requires more than J40 components.

6. Similarly, work stations processing more than J40 components are sub-divided into two or more work stations.

7. Sub-assemblies are assigned the same stock number as the final assemblies.

The following sequence of steps are suggested for structuring the model of a production system, keeping in view the above mentioned restrictions. This also aids in determining the data necessary for simulation. The procedure delineated herein is in context to the TV industry under study.

TABLE 1

INVENTORY DESCRIPTION

SN	
1.	If Stage - Finished Product
2.	Printed Circuits
3.	Resistors - 35 different values.
4.	Condensors - 26 different values.
5.	Transistors - 6 different values.
6.	Diodes - 3 different values.
7.	Peaking Coils - 3 different values.
8.	Coils VIF - 6 different values.
9.	Coils SIF
10.	Trap Coils
11.	Discriminator
12.	Detector Can
13.	Test pin
14.	Wire Jumpers - 3 different values.
15.	Solder-Consumable Item
16.	Potentiometer.
17.	First Dummy Assembly.
18.	Second Dummy Assembly.
19.	Third Dummy Assembly.
20.	Fourth Dummy Assembly.

FIGURE 13a

ASSEMBLY DIAGRAM FOR IF STAGE

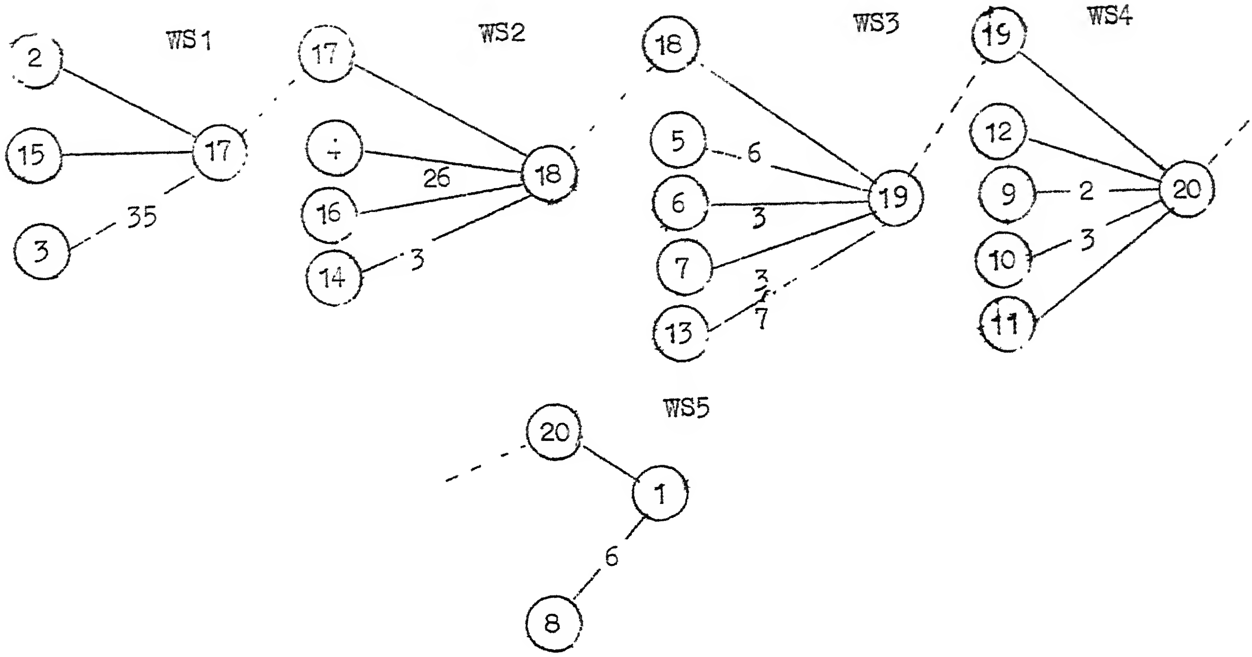
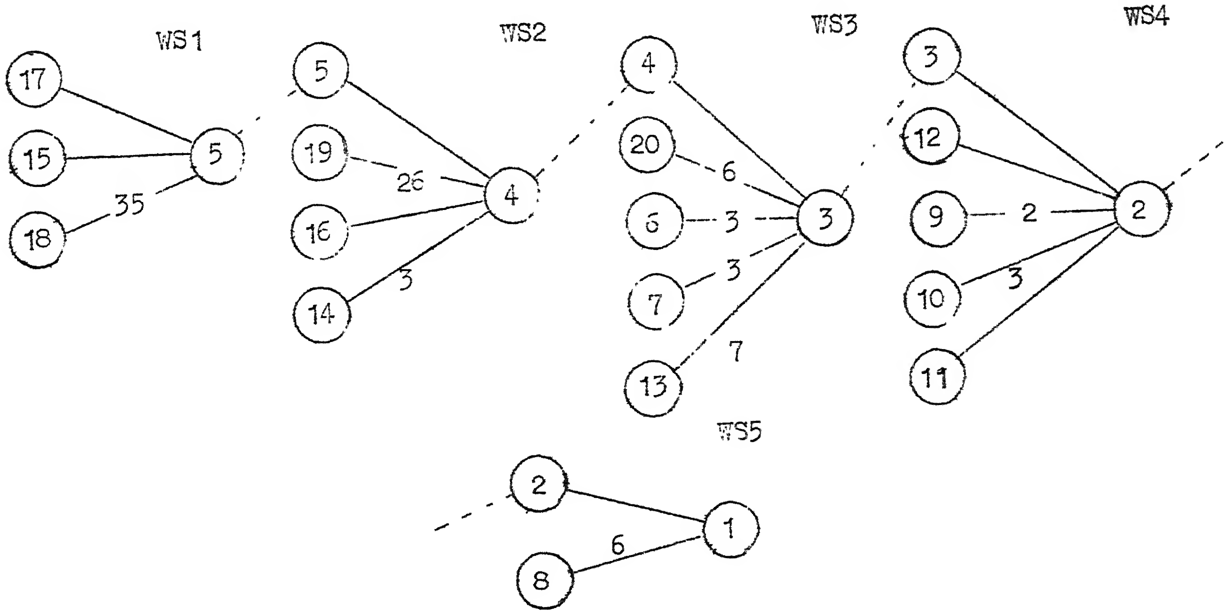


FIGURE 13 b

EXPLOSION CHART WITH RENUMBERED STOCK NUMBERS



WORK STATION LAYOUT	DESCRIPTION
17	
W.S. 1	Solder 35 Resistors
17	
18	
W.S. 2	Solder 26 Condensors, 3 Wire Jumpers and the Potentiometer.
18	
19	
W.S. 3	Solder 6 Transistors, 3 Diodes, 3 Peaking Coils and 7 Test Pins
19	
20	
W.S. 4	Solder 2 SIF Coils, 3 Trap Coils Discriminator and Detector Can
20	
1	
W.S. 5	Solder 6 VIF Coils
↓	
W.S. 6	Testing Sound Section and Repairs if required.
↓	
W.S. 7	Testing VIF Section, Tuning, Alignment and necessary repairs
↓	
1	

FIGURE 14

1. For production systems, where the number of work stations and stock numbers run into hundreds, analysis is carried out only for a particular product out of the several products being manufactured. Thus, in the present case, a particular sub-assembly called "IF STAGE" is selected for detailed analysis. This particular product was selected as the management considered it to be a bottleneck in the final assembly of TV sets. In addition, data for "IF STAGE" was easily available.

2. All inventory items were listed and unique stock numbers were assigned. Preferably, the stock numbers are so assigned that larger stock numbers go into the assembly of smaller stock numbers. This avoids renumbering of stock numbers for "Explosion Program" as explained in Appendix B. Items list for the production of "IF STAGE" is given in Table 1. The stock numbers are reduced by grouping different items together as shown in Table 1 i.e. resistors, condensors, transistors etc. of different values. Grouping can be done only for items requiring similar operations, same operation time, ordering costs and purchase orders.

3. The sequence in which the components are used in the production system has to be indicated. Specific work areas are established on the basis of machines or operators working in that work area. Each work area is assigned a work station number. The nature of work done and the components used at each work station are indicated in Figures 13a and 14.

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4. All operations are examined to find the maximum possible number of components (J40) required for an assembly. Dummy assemblies are created whenever the number of components required exceeds the maximum value of J40. The production of "IF STAGE" requires the assembly of 15 items. Therefore, the dummy assemblies labelled 17, 18, 19 and 20 had to be evolved.

5. Additional work stations were incorporated on similar grounds. The values of processing time, set-up time, in-process inventory, man rate and machine rate, of the original work station are divided between newly created work stations. For "IF STAGE" the original work station 4 processing 6 items has been divided into work stations 4 and 5 (Figure 13a).

6. Assembly diagram is drawn for each manufactured item (including the dummy assemblies) as shown in Figure 13a. For assembly of "IF STAGE", although solder is a consumable item required at five different work stations (Figure 14), it is allowed to enter the system at work station 1 only but is carried to other work stations as and when necessary (Figure 13a).

7. Figure 14 depicts the work station layout indicating the operations network for each manufactured item and the dummy assemblies. For "IF STAGE" the processed item at work stations 5, 6 and 7 is referred to as stock number 1 although, it has not been processed completely at these work stations.

8. For convenience, work station orders are tabulated as shown in Table 2.

TABLE 2

WORK STATION ORDER

Parameter PST (I, J, 4) IC = 1

WS

	I \ J	1	2	3	4	5	6	7
	1					1	2	3
SN	17	1						
	18		1					
	19			1				
	20				1			

TABLE 3 a

COMPONENT REQUIREMENTS

Parameter RMR (I, J, K) IC = 2

J	I			II			III			IV			V		
I \ K	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	20	1	5	8	6	5									
17	2	1	1	15	1	1	3	35	1						
18	17	1	2	4	26	2	16	1	2	14	3	2			
19	18	1	3	5	6	3	6	3	3	7	3	3	13	7	3
20	19	1	4	12	1	4	9	2	4	10	3	4	11	1	4

9. Table 3a gives raw material requirements as arrived at from Figure 13a. For each manufactured item, the table contains as many as J40 sets of data. Each set contains the information in the following order for each component :

   (i) Stock number of the component.

   (ii) Quantity of the component required for one unit or batch of the manufactured product.

   (iii) Work station at which the component enters the process.

10. Set-up times are determined for manufactured items at each work station. As the time increment used in the simulation is one minute, set-up times are assigned integer values (Table 4).

11. Processing times per unit or batch (also integers) are determined for each product at each work station (Table 5).

12. For each manufactured item the in-process inventory is determined in lots, corresponding to the respective work station. For dummy work stations this value is zero (Table 6).

13. The labour and machine rates for all work stations are tabulated for each minute of operation (Table 7). Machine costs are ascertained for working and idle conditions. For "IF STAGE" they are not different as the power is not disconnected when not soldering.

TABLE 3 b

EXPLOSION DATA WITH RENUMBERED STOCK NUMBERS

Parameter N (I, J) = IJ

	I		II		III		IV		V	
J	I	IJ	I	IJ	I	IJ	I	IJ	I	IJ
1	2	1	8	6						
2	3	1	12	1	9	2	10	3	11	1
3	4	1	20	6	6	3	7	3	13	7
4	5	1	19	26	16	1	14	3		
5	17	1	15	1	18	35				

TABLE 4

SET UP TIME IN MINUTES

Parameter PST (I, J, 2), IC = 1
Work Station

I \ J	1	2	3	4	5	6	7
1					5	15	15
17	10						
18		10					
19			10				
20				5			

TABLE 5

PROCESS TIME/UNIT (OR BATCH) IN MINUTES

Parameter PST (I, J, 1) IC = 1

Work Station

I \ J	1	2	3	4	5	6	7
1					9	10	15
17	18						
18		17					
19			13				
20				10			

TABLE 6

HOLD QUANTITY IN LOTS

Parameter PST (I, J, 3), IC = 1

Work Station

I \ J	1	2	3	4	5	6	7
1					1	1	1
17	1						
18		1					
19			1				
20				0			

TABLE 7

MAN AND MACHINES RATES IN Rs./MINUTE

Parameter OHR (I, J), IC = 3

WS

I \ J	1 Man	5 Machine Working	6 Machine Idle
1	0.015	0.0025	0.0025
2	0.015	0.0025	0.0025
3	0.015	0.0025	0.0025
4	0.008	0.0013	0.0013
5	0.007	0.0012	0.0012
6	0.020	0.0025	0.0025
7	0.030	0.0025	0.0025

14. The inventory information for "IF STAGE" is tabulated in Table 8. The unit costs of manufactured products are computed by summing up the unit costs of purchased items required to produce one unit of the manufactured product. Unit costs of purchased components are set equal to the regular purchase price. Carrying costs are assumed proportional to the unit costs. The discount prices are provided by the raw material supplier. Generally these values are 5 to 20 percent lower than the regular prices (3). For "IF STAGE" this value is 10 percent. The values of standard deviation of lead time are determined from past supply data. Generally the value of standard deviation does not exceed one third of the average value. Backorder or out of stock costs for finished products are generally 2 to 5 times the costs of the units (3). The value of initial stock on hand depends entirely on the management policies. This value is estimated by multiplying the average demand with the maximum lead time. Stock on hand is kept too high for items needing lesser investment.

15. The values of other parameters are determined in a manner outlined below and entered in Table 9 :

(a) The maximum value of stock numbers, work stations, J40 and the finished products are known from Table 1; Figures 13 a and 14. The values of production orders queue length before a work station depends on the particular production system.

TABLE 8

INVENTORY INFORMATION

Parameter ETAB (I, J), IC = 7

J	1	2	3	4	5	6	10	11	12	13	14	19
	2	10	0.26		300	67.44					200	1
	1	1	0.012	60.0	1500	6.00	6.0	5.4	8.0	2.0		
	1	1	0.00016	24.0	52500	0.08	0.08	0.072	8.0	2.0		
	1	1	0.00054	32.0	39000	0.27	0.27	0.24	8.0	2.0		
	1	1	0.008	60.0	9000	4.00	4.00	3.6	8.0	2.0		
	1	1	0.0025	60.0	4500	1.25	1.25	1.125	8.0	2.0		
	1	1	0.0005	31.0	4500	0.25	0.25	0.225	8.0	2.0		
	1	1	0.0035	70.0	9000	1.75	1.75	1.575	8.0	2.0		
	1	1	0.0035	70.0	3000	1.75	1.75	1.575	8.0	2.0		
10	1	1	0.002	58.0	4500	1.00	1.00	0.9	8.0	2.0		
11	1	1	0.006	71.4	1500	3.00	3.00	2.7	8.0	2.0		
12	1	1	0.0012	60.0	1500	0.60	0.60	0.54	8.0	2.0		
13	1	1	0.00004	8.0	10500	0.02	0.02	0.018	8.0	2.0		
14	1	1	0.00002	5.0	4500	0.01	0.01	0.009	8.0	2.0		
15	1	1	0.0033	68.0	1500	1.65	1.65	1.485	8.0	2.0		
16	1	1	0.0014	56.0	1500	0.70	0.70	0.63	8.0	2.0		
17	2	10	0.0209			10.45						1
18	2	10	0.0364			18.20						1
19	2	10	0.092			46.84						1
20	2	10	0.112			56.94						1

(Table continued)

TABLE 8 (Contd.)

EXPLANATION OF COLUMNS :

Column	Description
1	Code indicating whether the item is purchased (1) or or manufactured (2).
2	Lot size.
3	Carrying cost per unit per week in rupees.
*4	Reorder cost per order in rupees.
5	Initial stock on hand in number of items.
6	Unit cost in rupees.
*10	Regular price per unit in rupees.
*11	Discount price per unit in rupees.
*12	Average lead time in number of weeks.
*13	Standard deviation of lead time in number of weeks.
**14	Out of stock cost per unit per week in rupees.
***19	Batch quantity.

* Applies only to purchased items.

** Applies only to finished goods.

*** Applies only to manufactured items.

TABLE 9

PRODUCTION OF "IF STAGE"

Costs, Parameters, and Constraints.

a.	Number of Stock Numbers (I50)	20
b.	Number of Work Stations (J50)	7
c.	Maximum number of components permitted per SN (J40)	5
d.	Queue size at all work stations (LQ)	20 orders.
e.	Number of finished goods (NT)	1
f.	Number of allowed outstanding purchase orders (NOO)	200 orders.
g.	Number of sub-periods (ISP)	6
h.	Number of expected runs (IROW)	25
i.	Starting time period (ITP)	1
j.	Shift change cost per work station (SC)	-
k.	Fixed overhead per week (OH)	Rs. 3,000
	Variable overhead (VOH) ----- 0.4 times total labour cost.	
l.	Initial number of shift minutes (NMS)	480
m.	Random number generator seed values in generating random demand values (IX) 76500267 and random lead time values (IP) 76500267.	
n.	Maximum allowable inventory (PINVTY)	Rs. 1,50,000
	Penalty factor of excess inventory (VINVP)	0.25
o.	Actual average unit production cost of final product (ACUNCO)	Rs. 80
	Actual average weekly inventory costs (ACINVM)	Rs. 1,200
p.	Number of minutes in one time increment (TINC)	1
q.	Factor of Discount Order Quantity (FDOQ)	1.2

(b) The number of allowable outstanding purchase orders (NOO) depends on the purchase policy of the management, lead time of the items and the suppliers policy. If the number of purchased components is high, a high value of NOO is chosen to avoid shortages.

(c) Number of sub-periods represents the number of working days per week.

(d) Expected number of simulation periods is the planning horizon for which demands have been estimated. Care is taken to select this value such that capacity of the production system is not grossly exceeded during this time period.

(e) Simulation periods are numbered similar to the demand values. Hence, the value of starting time period is specified as one.

(f) Shift change cost includes the cost of changing personnels and an arbitrary penalty for haphazard change. This value is not known for 'IF SEAGE', since at present the industry under study works for only one shift during each day.

(g) High values of seeds are chosen to generate random numbers. This prevents the random numbers from approaching the zero values. The random numbers of zero values create computational difficulties in calculating normal deviate values for demand and lead time.

(h) Time increment used in the simulator is the highest common factor of the various processing and set-up times.

In addition to the above mentioned data values, others shown in Table 9 are determined for the particular production system under study. These data values are necessary for the initialization of the simulator. Punched output of the supplementary computer programs - "Explosion Program" and "Forecaster Program", are also used as input data for the simulator. After initialization, MOD-PROSIM V requires demands as input data during the simulation run. These values are specified in the second column of Table 15.

CHAPTER VI

RESULTS AND DISCUSSIONS

The working of the MOD-PROSIM V simulator has been tested with the help of the data obtained from J.K. Electronics. The following parameters are accounted in the simulator in order to develop the model for the production system under study :

1. The period of simulation is kept as one week comprising of six working days. This is done due to the fact that a weekly planning period is observed in J.K. Electronics. Weekly demands are generated and production planning is done accordingly.
2. The entire simulation run consists of 25 simulated periods. The planning horizon of 25 weeks is choosen so as to conform with the actual conditions prevalent for the 'IF STAGE' product at J.K. Electronics. 'IF STAGE' is a newly introduced product for the assembly of TV sets. Hence, the past demands are available for only 25 weeks. This planning horizon is considered sufficient to analyse the system's behaviour as events for every minute are simulated.

The forecasted demand of 'IF STAGE' is determined from the past production data. It is assumed that the production data provide good approximations to the demand and sales figures. The forecasted demand is estimated by the forecaster model. As shown in Figure 15, a sudden drop in the production of 'IF STAGE' occurs from first week to the fifth week. This drop in production is

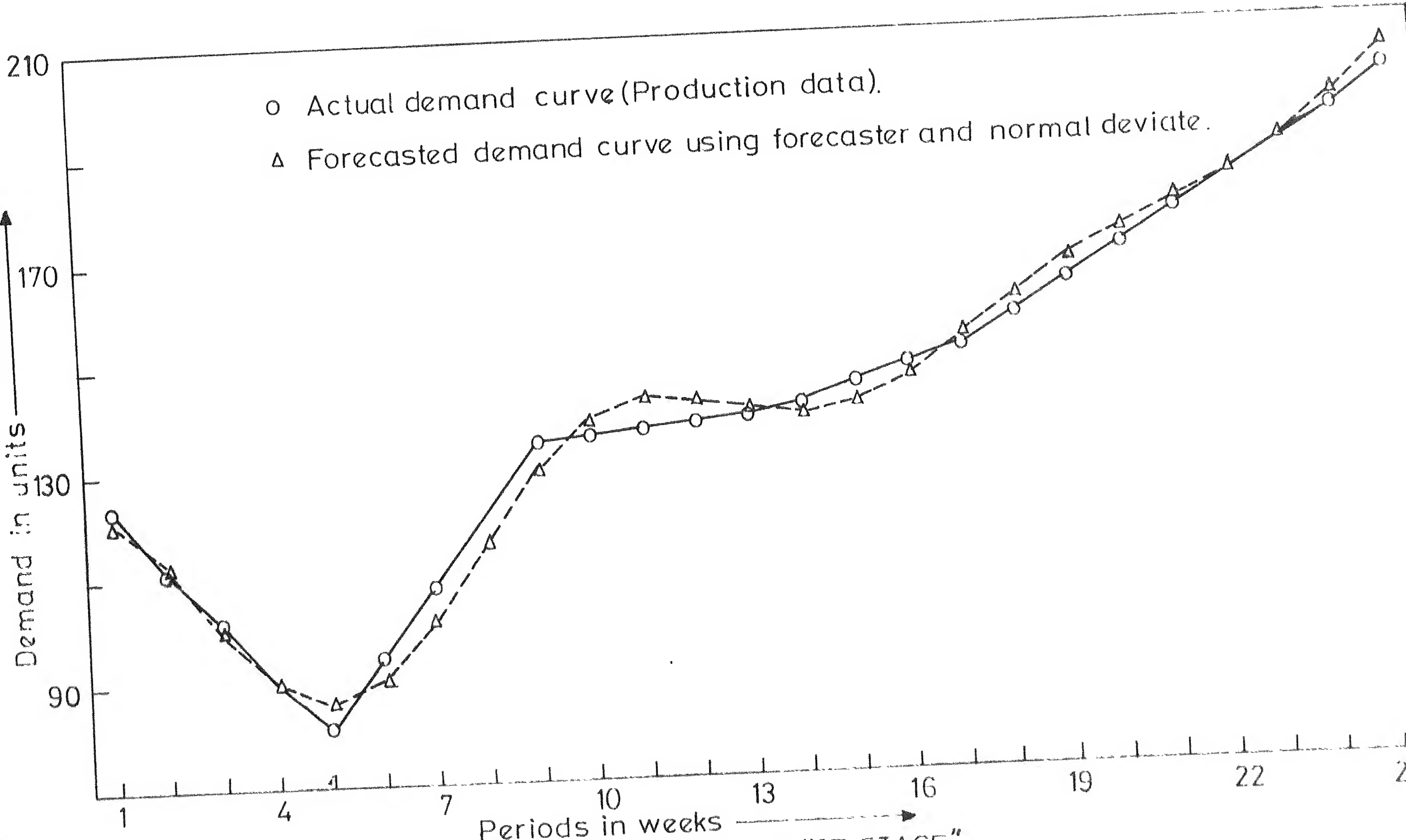


FIG. 15 ACTUAL AND FORECASTED DEMAND OF "IF STAGE".
(SALES)

attributable to the catastrophic events of strike and labour troubles during these periods. These periods have also been included in the past demand data in order to test that such events can be taken care of by the proposed simulator.

6.1 Accuracy of the Demand Forecaster

The various decisions made in a production system are either directly or indirectly based on the forecasts. Therefore, inaccuracies and errors in forecasts result in non-optimal decisions. Using the linear-quadratic-cyclic forecaster, the forecasted demands match closely with the actual production values for past data as is evident from Figure 15. Assuming that the past demand distribution has a bearing on the future demands, the proposed forecaster can be used for future planning of the production. The development of forecaster requires the estimation of the frequency of cycles as has already been discussed in Chapter III. The "Correlation and Spectral Analysis" is detailed in Appendix A. As mentioned earlier, these techniques have been used for the determination of frequencies.

6.1.1 Use of Correlation and Spectral Analysis

The past demand data of 'IF STAGE' are tested by calculating the different values of correlation coefficient (r_k) and smooth spectral density function (G_k) for various values of maximum lag number (m) - the value of m varied in the range of 3 to 22. This is done in order to select a proper value maximum lag number (m) by

following "window closing procedure" as explained in Appendix A. The values of r_k and G_k are analysed for different values of m. The significant results are observed when m reaches the values of 6, 9 and 19. The values of correlation coefficient (r_k) and smooth spectral density function (G_k) are tabulated (Tables 10 to 12) for the significant values of m.

Correlogram of past demand data does not indicate any significant periodicity within 95% confidence interval as is observed in Figure 16. But, non-randomness of the time-series is indicated by the non-zero values of r_k. The smooth power spectra for the maximum lag value of 6 indicates the demand as a simple Markov process, as shown in Figure 17. When maximum lag has a value of 9, a spike in the power spectra indicates the periodicity of 3. Again a periodicity of 3 is obtained by using maximum lag value of 19. However, the spikes in power spectra for periodicity of 3 are found outside the lower control limit of 95% confidence level. The only significant spike observed in the power spectra within control limits represents the periodicity of 9 for the maximum lag value of 19 (Figure 17).

Correlation analysis indicates insufficient data values to identify periodic components. But, the presence of an autocorrelated time series is observed. Spectral analysis identifies the presence of only one cycle of 9 periods with 95% confidence level in the past demand distribution. To confirm the periodicity of 9 and to identify other significant cycles, the iterative procedure as discussed in Chapter III is followed.

TABLE 10

CORRELATION AND SPECTRAL ANALYSIS

Maximum Lag (m) = 6

S.No.	Lag k	Correlation coefficient r_k	Smooth Spectral Density Function G_k	Frequency f
1	0	1.0000	130799.60	0.0000
2	1	0.9748	56707.68	0.0833
3	2	0.9204	1082.54	0.1666
4	3	0.8503	407.71	0.2500
5	4	0.7834	233.46	0.3333
6	5	0.7699	200.94	0.4166
7	6	0.7764	174.84	0.5000

CORRELOGRAM : N = 25 Mean = μ = -0.0417

Standard Deviation = σ = 0.1998

For 95% Confidence Level -

Upper Limit (UL) = 0.3500

Lower Limit (LL) = - 0.4333

POWER SPECTRA : ν = 7.6667

Mean = $\overline{G}_f$ = 27086.69

For 95% Confidence Level -

$x^2_{2.5\%,\nu}$ = 2.0 $x^2_{97.5\%,\nu}$ = 17.1

Upper Limit (UL) = 60400.0

Lower Limit (LL) = 9660.0

TABLE 11

CORRELATION AND SPECTRAL ANALYSIS

Maximum Lag (m) = 9

S.No.	Lag k	Correlation Coefficient r_k	Smooth Spectral Density function $\bar{I}_k$	Frequency f
1	0	1.0000	194998.39	0.0000
2	1	0.9748	84444.60	0.0556
3	2	0.9204	1783.22	0.1111
4	3	0.8503	1011.73	0.1667
5	4	0.7834	467.61	0.2222
6	5	0.7699	258.76	0.2778
7	6	0.7764	224.78	0.3333
8	7	0.7925	229.10	0.3889
9	8	0.8324	174.50	0.4444
10	9	0.8290	171.82	0.5000

POWER SPECTRA : $\nu = 4.8889$ $\bar{I}_f = 28376.45$

$x^2_{2.5\%,\nu} = 0.79$ $x^2_{97.5\%,\nu} = 12.5$

UL = 72500.0

LL = 4580.0

TABLE 12

CORRELATION AND SPECTRAL ANALYSIS

Maximum Lag (m) = 19

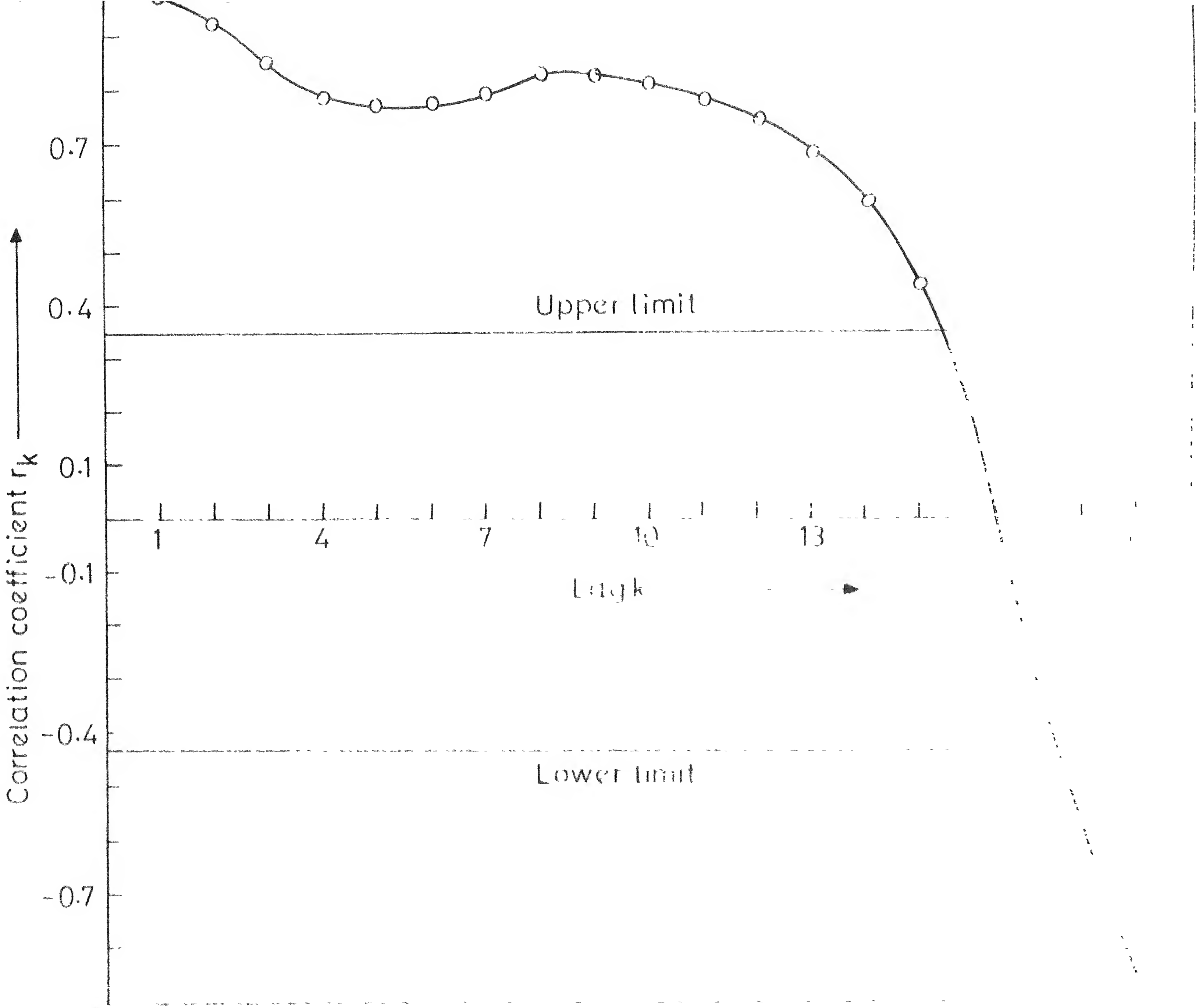
S.No.	Lag k	Correlation Coefficient r_k	Smooth Spectral Density Function G_k	Frequency f
1	0	1.0000	405489.84	0.0000
2	1	0.9748	177488.69	0.0263
3	2	0.9204	2991.94	0.0526
4	3	0.8503	1776.90	0.0789
5	4	0.7834	1811.03	0.1053
6	5	0.7699	1601.07	0.1316
7	6	0.7764	1199.98	0.1579
8	7	0.7925	576.02	0.1842
9	8	0.8324	520.68	0.2105
10	9	0.8290	321.72	0.2368
11	10	0.8112	304.76	0.2632
12	11	0.7828	157.14	0.2895
13	12	0.7455	219.65	0.3158
14	13	0.6839	223.46	0.3421
15	14	0.5915	284.36	0.3684
16	15	0.4390	238.89	0.3947
17	16	0.2016	175.26	0.4211
18	17	-0.2220	150.47	0.4474
19	18	-0.5559	156.96	0.4737
20	19	-0.8605	203.01	0.5000

POWER SPECTRA : $\nu = 1.9649$ $\quad \bar{G}_f = 29794.59$

$x^2_{2.5\%,\nu} = 0.05$ $\quad x^2_{97.5\%,\nu} = 7.1$

UL = 108200.0

LL = 758.0



0.7
0.4
0.1
-0.1
-0.4
-0.7
Correlation coefficient r_k
Upper limit
Lower limit
1
4
7
10
13
Lag k

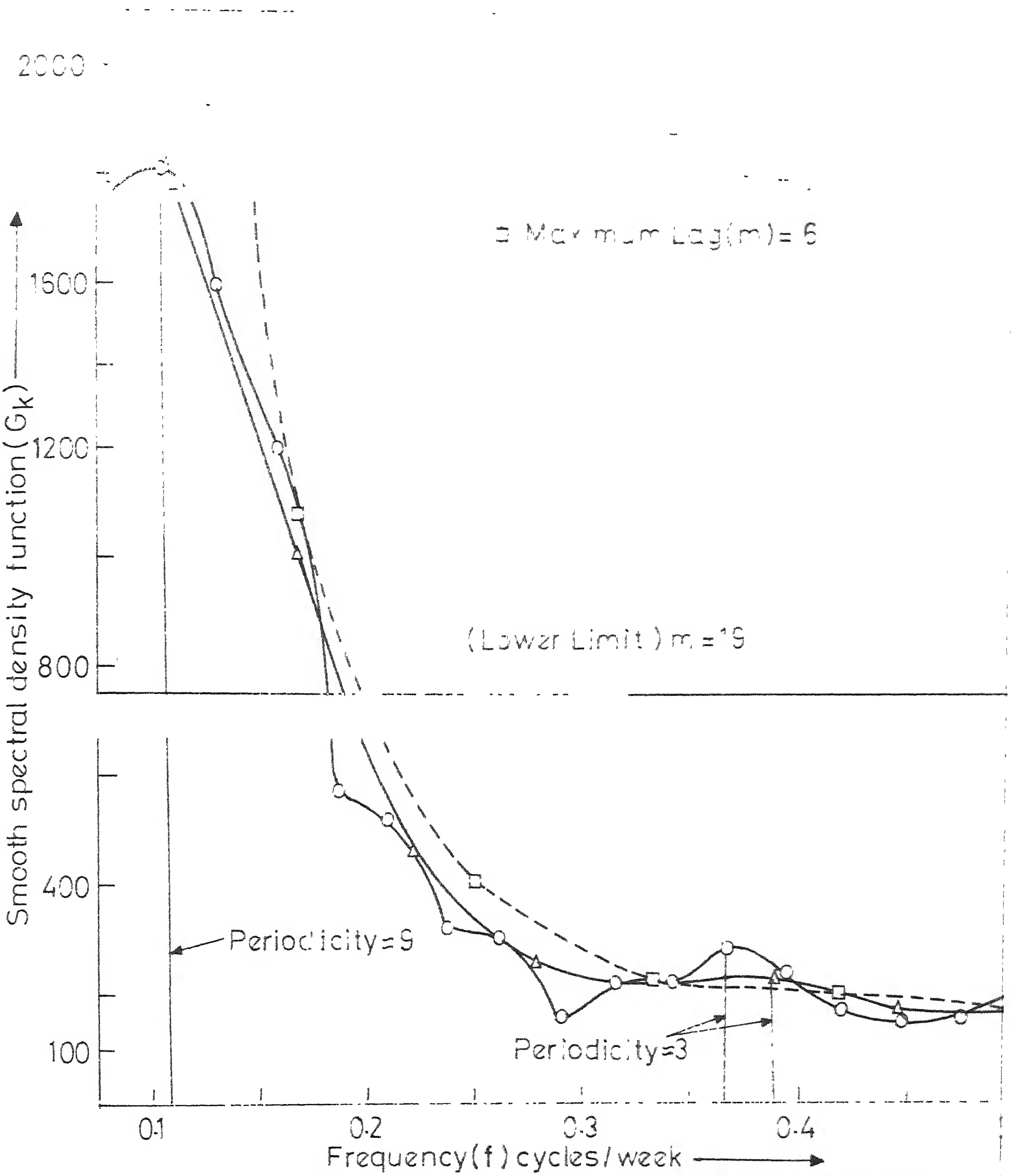


FIG.17. SMOOTH POWER SPECTRA OF PAST DEMAND DATA (SALES)
(95% confidence level)

6.1.2 Use of Iterative Procedure

By using the iterative procedure the periodicities of the three cycles in time-series are found to be 9, 11 and 14 periods (Table 13). The periodicity of 9 is also confirmed by the spectral analysis. The most significant cycle has the periodicity of 11 and an amplitude coefficient of 11.09. The least significant cycle has periodicity of 14. Regression analysis also generates the estimates of other demand parameters for minimum absolute error in forecasting. The demand coefficients are tabulated in Table 13.

The total absolute error in forecasting for the 25 past weeks is 65. The total actual demand for these periods is 3505. Thus the forecaster gives an error value of 1.85% over 25 periods. The value of standard deviation of demand is 3.16 for the average demand of 140 units of the finished product. In percentage this gives a value of 2.33. As shown in Figure 15, the forecasted values tally pretty well with the actual demands. This comparison has been carried out for 99.73% confidence level in forecasted demands. The forecasted and actual demand values for 'IF STAGE' are tabulated in Table 15 and the absolute difference per period for them is plotted in Figure 18.

6.2 Utility of the Inventory Policy

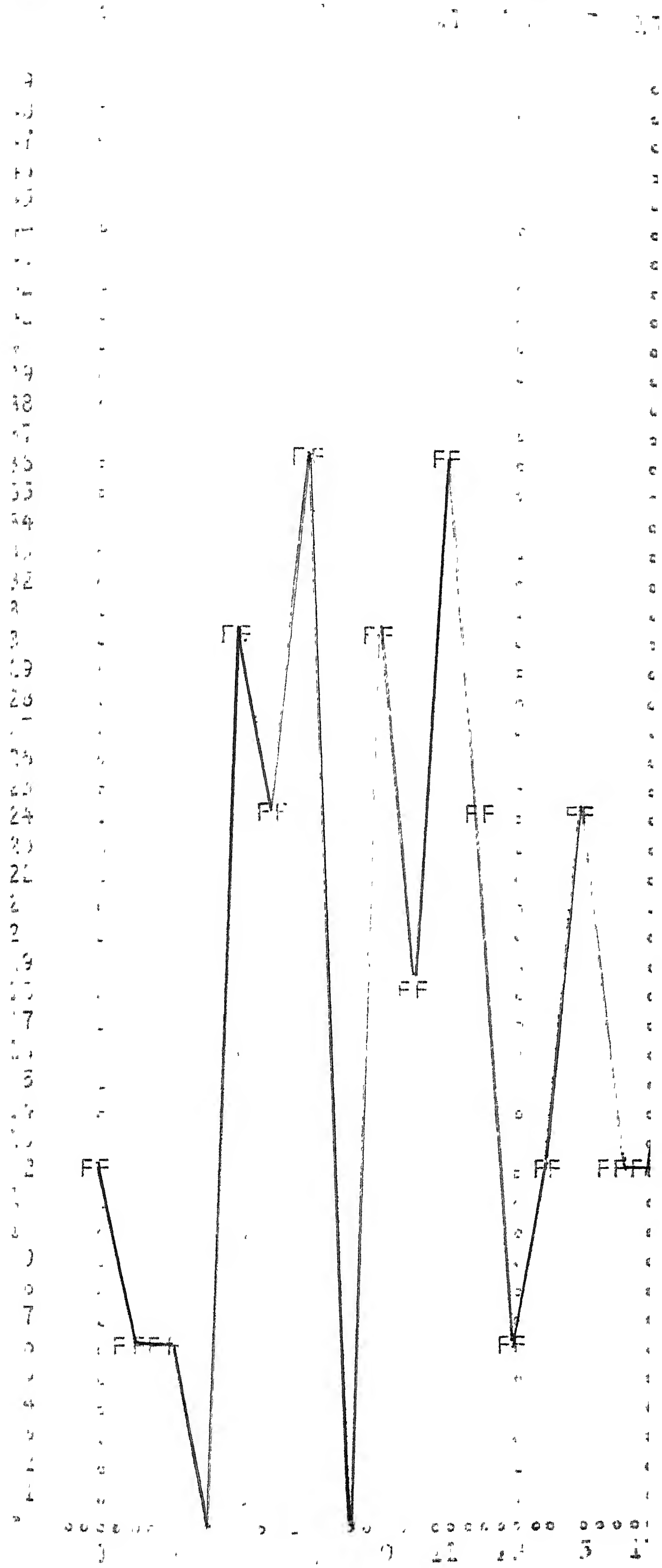
The inventory policy followed currently for the production of 'IF STAGE' is to keep initial stocks to meet the demand during the entire planning horizon i.e. 25 weeks. The purchase orders for raw materials are placed at regular time intervals of 16 weeks

TABLE 13

FORECASTER PARAMETERS

I = 1 For "IF Stage"

IC	Variable	Value
11	A (I)	97.644529
12	B (I)	1.563497
13	C (I)	0.104899
14	D (I)	7.833483
15	E (I)	4.5
16	F (I)	11.085214
17	G (I)	5.5
18	H (I)	6.752066
19	U (I)	7.0
20	AK (I)	3.162278



PLOT CHARACT ... PR...SENT ABSOL...
V...RTICAL SCAL... DOTS = 1 UN...

to meet the forecasted demands. This results in large investments in initial stocks. The inventory carrying costs are also increased significantly.

The proposed inventory policy generates the pertinent inventory parameters for the inventory model. The parts requirements of finished products are calculated by employing "Explosion Model". The estimated values of the inventory parameters for each purchased item are listed in Table 14. Initial stocks are maintained for the increase in demand considering the variable lead time for each purchased item. Sufficient raw materials are maintained at the time period zero to meet the average demand during the maximum possible lead time of each purchased part. For 'IF STAGE' this inventory policy results in reduction of initial stocks from about Rs. 7,00,000 to Rs. 1,21,342. This represents the seven fold improvement over the inventory policy currently used for 'IF STAGE'.

The simulation results in significant improvement of the total inventory costs over the actual inventory costs (average). This improvement in inventory cost increases from 16.84% in first week to 34.17% in the 25th week of simulation, as shown in Figure 19. These improvements in inventory costs are obtained mainly due to the reductions in inventory carrying costs.

6.3 Effectiveness of MOD-PROSIM V

The main performance measure of MOD-PROSIM V is the "Unit Production Cost (UPC)" of the finished products. In calculating the

TABLE 14

INVENTORY PARAMETERS FOR PURCHASED ITEMS

a. Longest Process Time = 18 Minutes

b. Estimated Plant Capacity = 160 pieces per week

c. Factor of Discount Order Quantity = 1.2

Renumbered Stock Number	Actual Stock Number (I)	Unit Requirement of SN 1 (IR)	Maximum Weekly Usage Rate (R)	EOQ	DOQ FTAB (I,9)
17	2	1	160	1267	1518
18	3	35	5600	40988	49185
19	4	26	4160	22204	26645
20	5	6	960	3795	4554
6	6	3	480	4800	5760
7	7	3	480	7715	9258
8	8	6	960	6197	7436
9	9	2	320	3578	4293
10	10	3	480	5276	6332
11	11	1	160	1951	2342
12	12	1	160	4000	4800
13	13	7	1120	21166	25399
14	14	3	480	15492	18590
15	15	1	160	2568	3081
16	16	1	160	3578	4293
5*	17	1			
4*	18	1			
3*	19	1			
2*	20	1			

*Manufactured Item

RAPHICAL REPRESENTATION OF RESULTS

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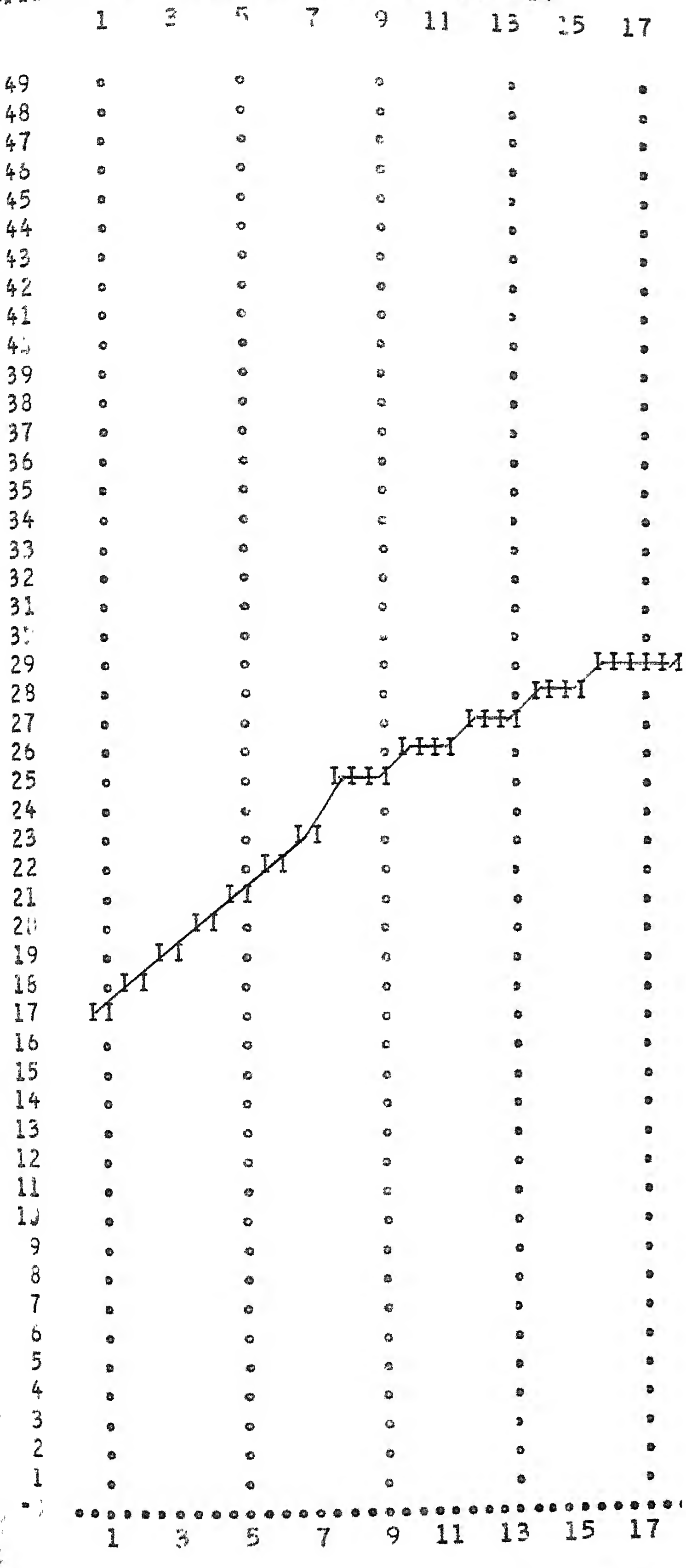

PLOT OF PERCENTAGE IMPROVEMENT IN
VERTICAL SCALE IS ONE DOT = 1.0 PE

values of UPC, all relevant costs (Refer Chapter II for details) are included, except the overheads. Allocation of overheads to any one particular product out of the several products being manufactured, is the most difficult task faced by the industries.

The value of UPC/week is calculated from the cumulative average of the costs over past periods. Figure 20 represents the improvement in UPC over the actual value (average). This improvement is due to the reduction in inventory costs. In the first week of simulation the improvement in UPC is only 6.14% as compared to the 13.86% achieved in the second week. This is due to the fact that cost of initial stocks and other overhead costs are contributed to the value of UPC in the first period of simulation.

The UPC of 'IF STAGE' increases from second period of simulation onwards to the last simulated period (Table 15). This also causes the drop in the percentage improvement as shown in Figure 20. This is due to the fact that the costs of purchased items are also included in calculating the value of UPC for each period. The parts for which purchase orders are placed in the initial periods start arriving only during the later periods.

The effectiveness of MOD-PROSIM V is also judged by analysing the values of percentage utilization of production capacity and the total plant operating costs during each of the simulated periods. The values of these variables have been plotted with respect to time in Figure 21 and 22. The characterstics of these

GRAPHICAL REPRESENTATION OF RESULTS
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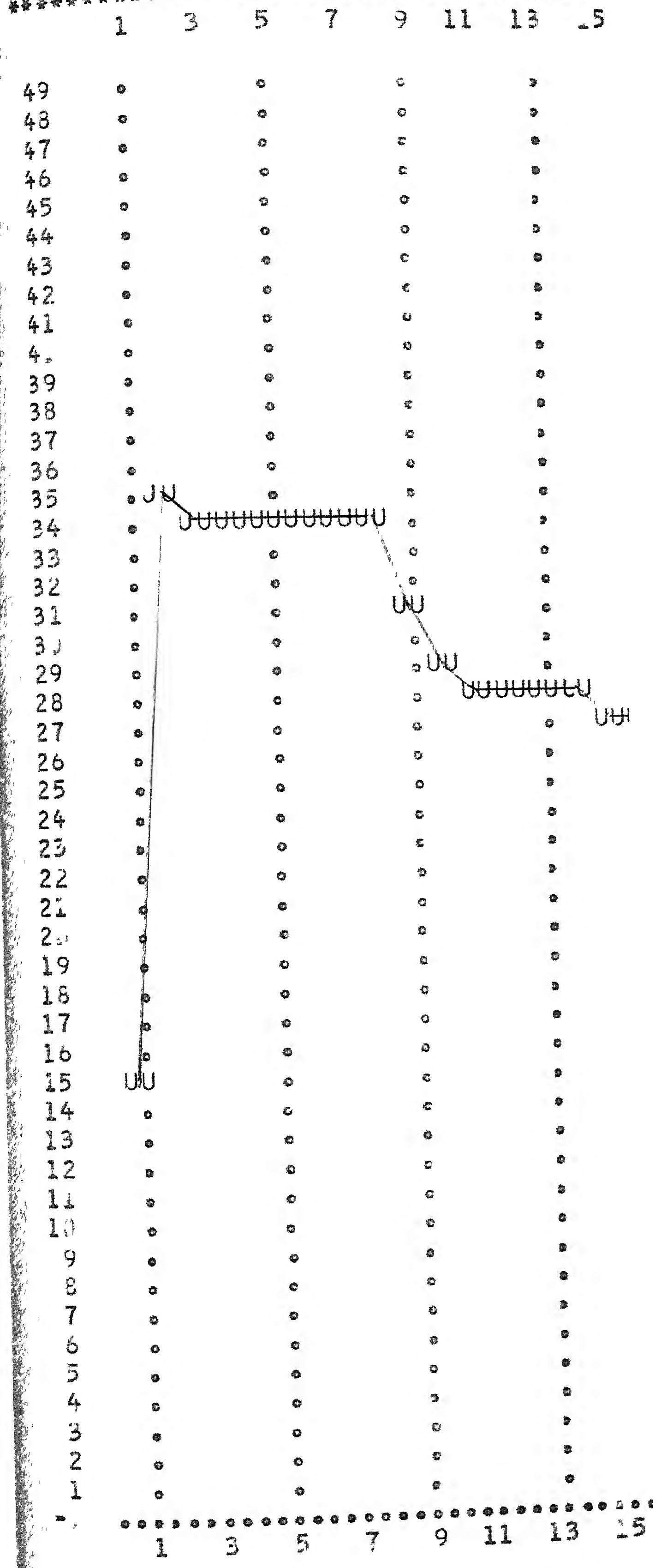


NO. OF

PLOT OF PERCENTAGE IMPROVEMENT
VERTICAL SCALE IS ONE DOT = 0.

TABLE 15

RESULTS OF SIMULATION RUN

(i) Actual Average Unit Cost = Rs. 80.00

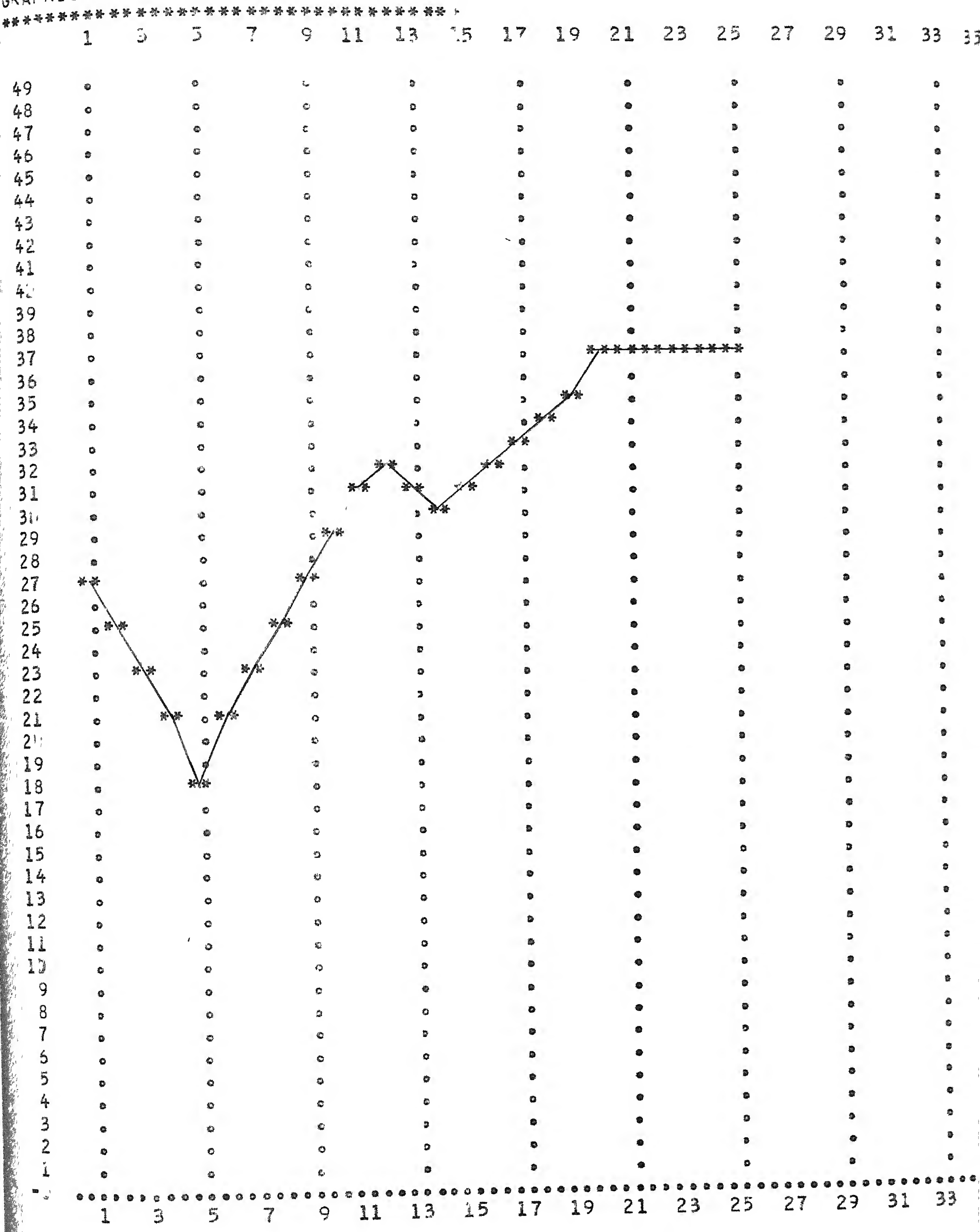
(ii) Actual Average Weekly Inventory Cost = Rs. 1,200.00

(iii) Calculated Weekly Out of Stock Cost = Rs. 0.00

(iv) Total Weekly Penalty = Rs. 0.00

No. of Week	Actual Weekly Demand	Fore-casted Weekly Demand	Average Unit Cost Rupees	Inventory Carrying Cost Rupees	Total Inventory Cost Rupees	Total Production Time Minutes	Total Inventory Value Rupees	Weekly Plant Cost Rupees	Cumulative Plant Cost Rupees
1	2	3	4	5	6	7	8	9	10
1	123	121	75.09	264.48	997.88	11080	114769.09	12578.73	12578.73
2	111	111	68.91	250.23	983.63	10150	106183.99	11887.42	24466.15
3	101	99	69.01	237.08	970.48	8280	99522.47	10526.80	34992.95
4	90	90	69.08	223.97	957.37	8280	93472.71	10513.69	45506.64
5	81	86	69.14	212.25	945.65	7360	87681.68	9827.56	55334.20
6	94	90	69.18	199.48	932.88	8280	81623.74	10489.20	65823.40
7	107	101	69.21	185.60	919.00	9200	74817.73	11149.71	76973.12
8	115	115	69.22	169.67	903.07	10120	67057.28	11808.19	88781.31
9	134	129	70.00	164.63	898.03	11020	77737.14	12478.44	101259.75
10	135	138	70.86	159.65	893.05	11760	72108.58	15292.81	116552.56
11	136	142	70.90	152.83	886.23	12500	67373.15	15400.85	131953.40
12	137	141	71.01	145.92	879.32	12880	63157.27	15353.27	147306.68
13	138	139	71.12	139.00	872.40	12340	59590.75	14625.04	161931.71
14	140	138	71.20	131.32	864.72	11960	55809.29	14474.69	176406.40
15	144	140	71.27	124.55	857.95	12500	52044.97	15099.99	191506.39
16	147	145	71.38	120.11	853.51	12880	49589.78	15165.89	206672.28
17	150	152	71.49	115.79	849.19	13240	47185.88	15530.15	222302.43
18	156	159	71.59	111.96	845.36	13800	45468.14	15801.39	238103.82
19	162	166	71.68	107.33	840.73	13980	43376.26	15947.95	254051.77
20	168	171	71.78	102.00	835.40	14720	[illegible]	16558.59	270610.36
21	175	176	71.87	95.59	828.99	14720	38137.16	16389.61	286993.96
22	181	181	71.95	87.73	821.13	14720	34922.18	16341.65	303335.61
23	187	187	72.02	78.62	812.02	14720	31434.04	16304.67	319640.28
24	193	195	72.09	68.25	801.65	14720	27745.40	16269.17	335909.45
25	200	204	72.16	56.55	789.95	14720	23928.00	16232.80	352142.25

GRAPHICAL REPRESENTATION OF RESULTS

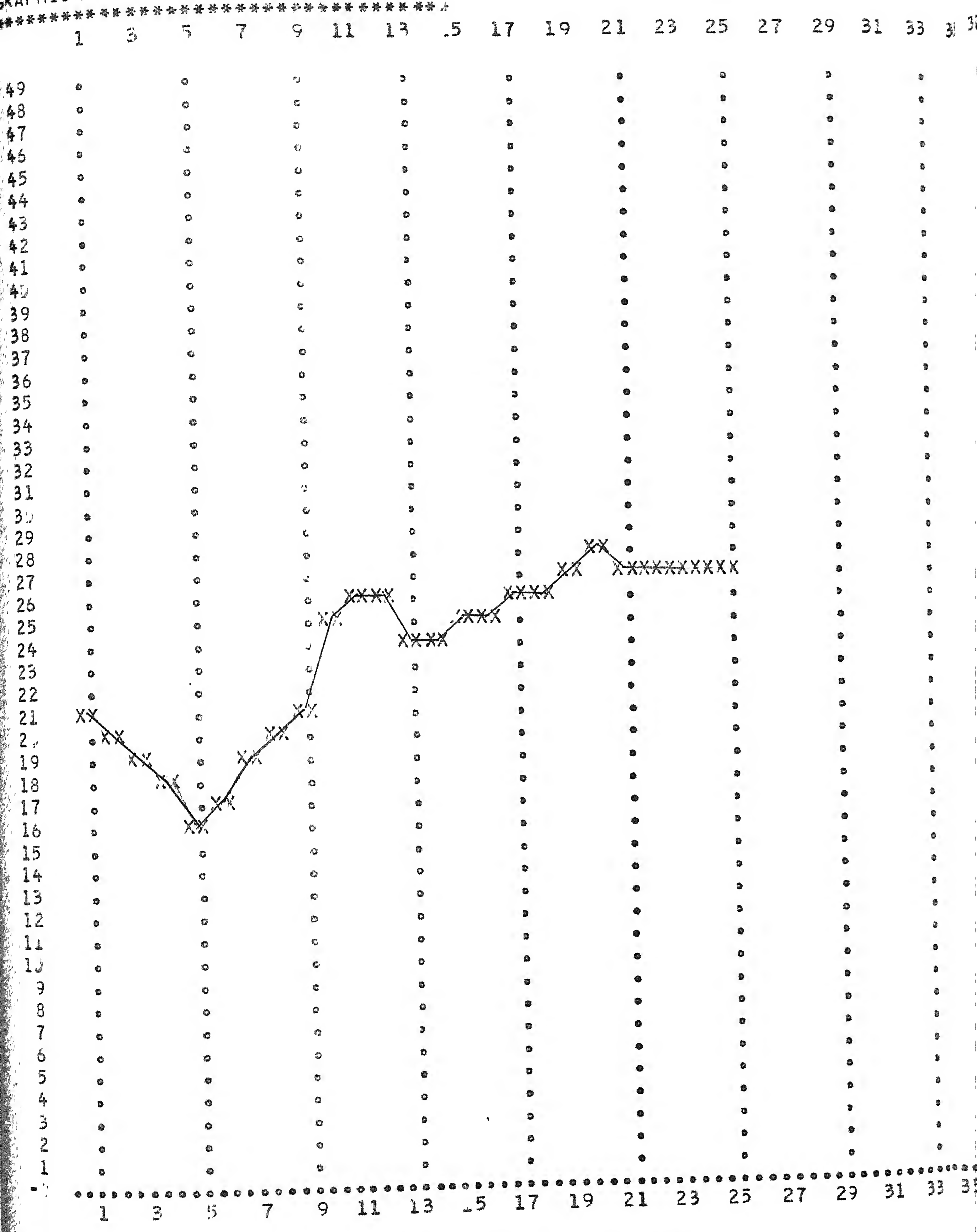


NO. OF WEEKS ---------

PLOT OF PERCENTAGE UTILISATION OF PRODUCTION CAPACITY
VERTICAL SCALE IS ONE DOT = 2 PERCENT OR ONE INCH = 12 PERCENT

FIG. - [redacted] 21

GRAPHICAL REPRESENTATION OF RESULTS



PLOT OF PLANT OPERATING COST. VERTICAL SCALE IS ONE INCH =RS3600 OR

FIG. - 22

closely resemble those of the demand distribution (Figure 15). This indicates that the demand distribution may be treated as representative of the system performance.

In calculating the values of plant operating costs for each period the approximate values of overhead costs have also been included. The plant operating costs could not be compared with the actual values. This is due to the difficulties faced in estimating actual plant costs, since the allocation of overheads to a particular product could not be determined.

MOD-PROSIM V simulates the production system for each minute. For 'IF STAGE' the simulation is carried out over 25 weeks. This is quite a considerable period for the system to stabilise. The external perturbations settle down sufficiently over the simulation period. The initial disturbances in the demand of 'IF STAGE' due to strikes etc. (Figure 15) causes disturbances in other variables also (Figures 20 to 22). But these fluctuations in the variables settle down considerably by the end of the simulation.

In addition to the effectiveness measures mentioned above, MOD-PROSIM V also provides the user with detailed reports. The printed reports for each period of simulation provides the production manager with the necessary information regarding the production system e.g., production status, inventory position, outstanding purchase orders etc. This facilitates him in making both short-term and long-term decisions.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

7.1 Conclusions

MOD-PROSIM V incorporates various important functions of the production systems. The functions considered are forecasting, inventory control and production planning. The simulator generates a set of decision policies. These decision rules provide the management with certain guidelines for rational planning. In developing the model an attempt is made to achieve an "adaptive" control system-one that monitors its own performance and at least partially updates its own parameters. Every care has been taken to incorporate the realistic features of a production system in MOD-PROSIM V.

The following inferences are drawn from this study :

1. The simulator uses cost minimization as the optimization criteria. The various sub-objectives are satisfying customer demands, optimum plant utilisation etc.

2. The model structured for MOD-PROSIM V is very general - it permits application to varied manufacturing situations. The model is validated for the sub-system of a typical Indian industry manufacturing television sets.

3. The formulation and validation of the model for large complex production system is prohibitive due to the restriction imposed by the Computer for which the simulator has been developed.

4. Effectiveness of the simulator is best judged by carrying out a comparative analysis. The results obtained from the simulation run are compared with the actual performance of the production system.

5. Demand forecasting is an important feature of MOD-PROSIM V. A linear-quadratic-cyclic forecaster is used in the proposed model with capabilities of handling upto three cycles in the time - series. For the 25 weeks of past demands for the TV industry under study only 1.85% of forecasting error is found. Thus the proposed forecaster is sufficiently accurate and flexible for application to different types of demand distributions.

6. The inventory model developed in the simulator provides significant improvement over the inventory costs of the production system under study. By carrying out the simulation the investment in initial stocks are reduced by as much as seven times. The reduction in inventory costs varies from 16.84% to 34.17% over the simulation run of 25 weeks.

7. The simulator provides an overall view of the operation of production system with respect to time. The production manager gets useful information for each simulated period e.g., production costs of final products, plant utilisation, total plant operating costs, production and inventory status etc.

8. The simulation is carried over a planning horizon to test the ability of the control system to respond and adjust to external

perturbations. The model as tested for the production system under study is found quite effective to take care of catastrophic events like strikes and labour troubles. The results of simulation indicate the presence of a responsive control system which results in significant improvement over the actual system performance. The system is found to be sufficiently stable over the planning horizon of 25 weeks, since the simulation period is a minute.

7.2 Recommendations for Further Work

There are several channels for extension in the present work. An attempt may be made to relax some of the assumptions made in developing the simulator. More realistic simulation would be achieved by incorporating the following features of production systems in MOD-PROSIM V :

1. The forecaster developed in the present model is capable of handling linear, quadratic and cyclic demands. Depending on the demand distribution of a particular product, the simulator can be modified to account for different trends (polynomial, logarithmic, exponential etc). When simulation is carried out over the entire life cycle of a product, then growth curves like Pearl and Gompertz (24) can be used to advantage for forecasting. This is generally done for products with short life cycle.

2. In the present work demand is considered only as a time dependent variable, since it's relationship with other variables is unknown.

In real life situations the demand of a product may have a correlation with several variables - seasonal sales, demands of other products etc. The forecaster can be modified to incorporate the multiple correlation of demand, if the inter-relationship and inter-dependence of variables is precisely known.

3. Processing times at work stations are not essentially deterministic. A random variable processing time can be considered for each of the operations. This requires the information regarding processing time distribution.

4. The quality (percent defective) of the incoming raw materials and of manufactured items in the production system affects the values of other variables. The quality can be considered as a random variable. This requires complete information and data connected with quality of all items e.g., parameters of quality distribution, quality control costs etc. The relationship of quality of items with other variables can be incorporated in the model.

5. In real life production systems the machines experience breakdowns. The breakdowns occur at random intervals and the repair time is a random variable. These features can be incorporated in the simulator if various parameters and distributions for plant maintenance are precisely known.

6. The proficiency of all machine operators is not same, as is assumed in the simulator. To improve on it, requires a thorough evaluation of each of the operators. After analysing the various human

and other factors, planning can be done for the operator's training, hiring, firing or replacement for cost minimisation criteria (7).

7. In the proposed model the assembly line is assumed to be balanced. An assembly line balancing algorithm can be accommodated in the simulator for any particular manufacturing system.

Each of the above mentioned features require an independent research in the related field. Incorporation of these features in the simulator, necessitates a thorough comprehension of the inherent complexities and inter-relationships prevalent in the system.

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APPENDIX A

CORRELATION AND SPECTRAL ANALYSIS

The parameters of any time series model can be estimated to greater accuracy if sufficient past data of the system are known. The stationarity of the model is also identified by using the data. Correlation and spectral analysis are two of the important tools in the identification of the periodic and persistence components of the time series.

Persistence refers to the linkage between successive members of a time series. The sequential dependence in a time series can be tested by autocorrelation analysis. The autocorrelation function of a time series describes the general dependence of the values of the data at one time on the values at another time. The sample value of the h^{th} serial correlation coefficient (r_h) between x_t and x_{t+h} can be calculated by -

$$r_h = \frac{\frac{1}{N-h} \sum_{i=1}^{N-h} x_i \, x_{i+h} - \frac{1}{(N-h)^2} \sum_{i=1}^{N-h} x_i \sum_{i=1}^{N-h} x_{i+h}}{s_i \cdot s_{i+h}}$$

$$h = 0, 1, 2, \text{-----}, m. \qquad (A-1)$$

where

N = total number of data values,

x_t = given time series at time t,

h = lag number,

m = maximum lag number,

s_i is the standard deviation which can be calculated by

$$s_i = \frac{1}{N-h}\sqrt{\left[\sum_{i=1}^{N-h} x_i^2 - \frac{1}{(N-h)^2}\left\{\sum_{i=1}^{N-h} x_i\right\}^2\right]} \qquad (A-2)$$

and s_{i+h} is given when x_{i+h} is substituted for x_i in the above equation.

The correlation coefficients (r_h) which are functions of h can be represented graphically. The graphical representation is called 'Correlogram'. The value of r_h as given by equation (A-1) does not depend on t since the process is assumed to be stationary. Though r_h is defined only for discrete values of h. The plotted points are generally joined by straight lines. The important properties of the autocorrelation function are summarized below :

1. $r_o = 1$, for $h = 0$
2. $|r_h| \leqslant 1$ for all h.
3. $r_h = r_{-h}$ i.e., r_h is symmetrical about $h = 0$.
4. For a pure random process $r_h = 0$, for $h \neq 0$, but for a finite sample in the random process, the computed values of r_h may be different from zero due to sampling errors. Generally for small sample sizes, the statistical testing can be done for the values of $h \ngtr N/10$. A series can be considered random if r_h is not significantly different from zero. For a circular random series, r_h is nearly normall distributed with a mean $- 1 / (N - 1)$ and a variance of $(N - 2) / (N - 1)^2$.

So the confidence limits for probability level $(1 - \alpha)$ are given by

$$\frac{-1}{N-1} - t_{(\alpha/2)} \frac{\sqrt{(N-2)}}{(N-1)} \leq r_h \leq -\frac{1}{N-1} + t_{(\alpha/2)} \frac{\sqrt{(N-2)}}{(N-1)} \qquad (A-3)$$

where $t_{(\alpha/2)}$ is the standardised normal variate for confidence level $(1 - \alpha)$. If the computed value of r_h lies within this interval, r_h is not significantly different from zero and the process can be considered as random with $(1 - \alpha)$ confidence level.

5. If cyclicity is present, then the correlogram will also be periodic with the same frequency.

6. For a simple Markov process, the correlogram is a monotonously decreasing curve, for $r_1 > 0$. For negative r_1 a strong high frequency oscillation with period unity is indicated and the correlogram has a decreasing but nonvanishing amplitude.

7. For a simple model with equal weights, the correlogram decreases with h and vanishes for $m \geq h$.

Autocorrelation function (r_h) establishes the influence of values at present time over the values at future time in the given data. A sine wave, or any other deterministic data, will have an autocorrelation function which persists over all time displacements, as opposed to random data which diminishes to zero for large time displacements. An autocorrelation measurement clearly provides a tool for detecting deterministic data which might be masked in a

random background. The details about a time series are generally better interpreted from the power spectral density function than from autocorrelation function.

The power spectral density function of random data describes the general frequency composition of the data in terms of the spectral density of its mean square value. The power spectrum density function is usually estimated as the Fourier transformation of the autocorrelation function r_h or the autocovariance function R_k (k^{th} autocovariance) given by -

$$R_k = \frac{1}{N-k} \sum_{i=1}^{N-k} (x_i - \overline{x}_i)(x_{i+k} - \overline{x}_{i+k}) + \overline{x}_i \cdot \overline{x}_{i+k}$$

$$k = 0, 1, 2, \text{-----}, m \qquad (A-4)$$

where

$\overline{x}_i$ = sample mean value of x_i

k = lag number

if the transformed record x_t is stationary with $\overline{x} = 0$, then transformed autocovariance function R_k is given by -

$$\hat{R}_k = \frac{1}{N-k} \sum_{i=1}^{N-k} x_i \cdot x_{i+k} \quad \text{then } -1 \leq \hat{R}_k \leq 1 \qquad (A-5)$$

For sampled data from a transformed record x_t which is stationary with $\overline{x} = 0$, a raw estimate of a true power spectral density function is defined for an arbitrary frequency f in the range $0 \leq f \leq f_c$ by -

$$\tilde{G}_x(f) = \frac{2}{m}\left[\hat{R}_0 + 2 \sum_{k=1}^{m-1} \hat{R}_k \operatorname{Cos}\left(\frac{\pi k f}{f_c}\right) + \hat{F}_m \operatorname{Cos}\left(\frac{\pi m f}{f_c}\right)\right] \qquad (A-6)$$

values. Hence it is necessary to smoothen the raw spectra.

There are several procedures available to obtain final practical smooth estimates which have more suitable statistical - - riability properties. The frequency smoothing is done with a procedure called "Hanning", for which the smooth spectra are given by (2) -

$$G_o = 0.54\ \tilde{G}_o + 0.46\ \tilde{G}_1$$

$$G_m = 0.46\ \tilde{G}_{m-1} + 0.45\ \tilde{G}_m$$

$$G_h = 0.23\ \tilde{G}_{h-1} + 0.54\ \tilde{G}_h + 0.23\ \tilde{G}_{h+1}, \quad h = 1,\ 2,\ ---,\ m-1 \tag{A-9}$$

A typical plot of power spectral density G_x (f) versus frequency f is called power spectra. In order to estimate a suitable value of maximum lag number m a "window closing procedure" is followed (3). The estimate is said to have high fidelity when for all frequencies, the bias (difference between the estimate and the true value) is small. For high fidelity, the bandwidth must be of the same order as the width of the narrowest important detail of the spectrum. This requires a small bandwidth B_e and a large m.

The estimate is said to have high stability if the variance of the estimator is small. High stability requires a large value for the degrees of freedom and hence a small value of m. Generally a compromise between these two requirements may be needed. As m decreases, the raw spectra is approached and spurious peaks increases.

where

f_c = cut-off or Nyquist frequency = $\frac{1}{2\,\Delta t}$

m = maximum value of lag number k.

Δt = time interval over time horizon T between N samples of discrete data.

$\hat{R}_o$ = value of transformed autocovariance function ($\hat{R}_k$) for zero lag number.

$\hat{R}_m$ = value of $\hat{R}_k$ for maximum lag number.

Since the values of $\tilde{G}_x$ (f) are calculated only at the m + 1 special discrete frequencies where -

$$f = \frac{h\, f_c}{m} \qquad h = 0,\ 1,\ 2,\ ---,\ m \tag{A-7}$$

At these discrete frequency points, the value of power spectral density function is given by

$$\tilde{G}_h = \tilde{G}_x\,(f) = \frac{2}{m}\left[\hat{R}_o + 2\sum_{k=1}^{m-1}\hat{R}_k \cos\left(\frac{\pi\, kh}{m}\right) + (-1)^h\,\hat{R}_m\right] \tag{A-8}$$

The index h is the harmonic number. This will provide m/2 independent spectral estimates of $\tilde{G}_x$ (f) which may be considered to be an average of the spectra over a bandwidth $B_e = \frac{2\,f_c}{m}$ around frequency f. Spectral estimates at points which are less than B_e apart are correlated. (1)*

$\tilde{G}_h$ has a negative exponential distribution and so the sample value of $\tilde{G}_h$ may be widely different from the true population

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*The references have been given at the end of the Appendix.

By comparison of the results with theoretical models and expected behaviour of the physical process, a suitable value of m may be chosen.

The general characterstics of the power spectra for several generating processes are summarized below -

1. A constant value time-series has no power spectrum.
2. A sloping line has non-zero value of power density function at zero frequency.
3. A simple harmonic time series has non zero values at appropriate frequencies in the power spectra.
4. For a pure random process, the spectral density, in the frequency range $0 \leq f \leq f_c$, is constant and is equal to the average of the $(m + 1)$ computed values of the raw spectrum. The sample spectral estimates are distributed about the population spectrum according to Chi-square Distribution. The number of degrees of freedom for spectral calculation $\nu = (2N/m) - (2/3)$. From tables of (x^2/ν) distribution, the confidence limits for a given level of confidence $(1 - \alpha)$ can be obtained. The series is pure random at $(1 - \alpha)$ level if,

$$\frac{x^2_{(\alpha/2),\nu}}{\nu} \bar{G}_x(f) < G_x(f) < \frac{x^2_{(1-\alpha/2),\nu}}{\nu} \bar{G}_x(f) \qquad \text{(A-10)}$$

where

$$\bar{G}_x(f) = \frac{\sum_{i=0}^{m+1} G_x(f)}{m+1}$$ = average of spectrum density function for pure random process.

5. For a simple Markov process the spectral density decreases continuously with the frequency for f $>$ 0.

6. For the general weighted moving average process the spectra is a sinusoidal distribution about the variance of the time series.

The principal application for a power spectral density function-measurement of physical data is, to establish the frequency composition of the data which, in turn, bears important relationships to the basic characterstics of the physical system involved. In the identification of the components of the time series, correlogram and spectral analyses are to be used complementary to each other. While correlogram may indicate the general nature of the components, adjacent values are not independent; while in spectra, they are nearly independent. Moreover details may be more clear in spectra than in correlogram.

The presence of periodic cycles in the time series will be indicated by the periodicity in the correlogram and spikes at appropriate frequencies in the spectral density function. Once the frequencies are identified other coefficients of time series can be estimated by using regression analysis. From the past data the values of autocorrelation function and smoothed power spectral density function are calculated, for different values of maximum lag number m. After plotting the power spectra for all these values of m, a suitable value of m can be decided which gives sufficient details to analyze the time series. The values of m may vary from

N/20 to a maximum value of N/2. The plot of correlogram remains same for all values of m and it should be preferably plotted for maximum value of m.

A computer program is available for autocorrelation, cross-correlation and spectral analysis (4). The program has been written in FORTRAN IV and the listing is included in Appendix C. The computer program input requires number of samples N, number of variables, past history data of time series and different values of m. The output results contain values of autocorrelation function, cross correlation function, raw and smooth spectra, frequency, upper and lower confidence limits for correlogram for 95% confidence level, degrees of freedom and mean value of smooth spectral density function $\bar{G}_x(f)$, for each value of m. Sufficient number of COMMENT Cards have been sprinkled to aid the user in understanding the general flow of control within the program.

References :

1. Bendat, J.S. and A.G. Piersol, Random Data Analysis and Measurement Procedures, Wiley - Interscience, 1971, pp 311 - 322.
2. Blackman, R.B. and J.W. Tukey, The Measurement of Power Spectra, Dover Publications, New York, 1958.
3. Jenkins, G.M. and D.G. Watts, Spectral Analysis and its Applications, Holden - Day, San Francisco, 1968, pp. 239 - 309.
4. Ramaseshan, S., Department of Civil Engineering, Indian Institute of Technology, Kanpur.

APPENDIX B

EXPLOSION PROCEDURE FOR PARTS DETERMINATION

Explosion procedure is an analytical tool for the conversion of sales forecasts to the estimate of production quantities. It is a systematic procedure based upon matrix algebra. It provides a good framework for performing the planning function by parts determination. This technique is specially useful when large numbers of products and parts are involved. In this procedure a Gozinto analysis is carried out for a final assembly by drawing explosion or Gozinto chart showing the relationships of components, materials and sub-assemblies (1).* This directed network indicates the order in which parts go into other parts to make the final product. Further it indicates the number of parts of each type needed to make one of the other type. From this the "Next Assembly Quantity Matrix (N)" is developed. The N matrix shows the bill of material relationships for all parts, finished or unfinished. In N matrix a row of zeros indicates a final assembly, while a column of zeros indicates a raw material or a detail part.

The goal in the explosion procedure is to calculate the "Total Requirement Factor" or "Matrix T", showing the total quantity of each part necessary for all sub-assemblies and assemblies. The diagonal elements of T matrix have values equal to unity. The relationship between T and N matrices is represented as :

---

* The references have been given at the end of the Appendix

$$T = [I - N]^{-1} \tag{B-1}$$

where

I = identity matrix of order equal to the total number of items (raw materials, sub-assemblies and finished products.)

An algorithm is available to compute the inverse of (I - N) matrix (2).

Even after using the $(I - N)^{-1}$ algorithm the number of calculations required in Gozinto analysis are quite large. In the "Explosion and Netting" procedure (3) for parts determination, the parts are renumbered so that large stock numbers always go into the assembly of small stock numbers. By doing this the N matrix becomes lower triangular matrix, for which inverse is easy to calculate. The calculations required in explosion and netting procedure are simplified by employing "Curado and Hassell's" algorithm (4). The latest effort in this field is the "Plug and Chug" technique (5), which further simplifies the Curado and Hassell's algorithm.

In Plug and Chug method the computations are done backwards. From relationship (B-1) it is clear that since N is a lower triangular matrix, T is also a lower triangular matrix with unit diagonal elements. The total requirement of the ith assembly or sub-assembly is given by the recurrence relationship :

$$T_i = \sum_{k=i+1}^{m} n_{ki} \; T_k + I_i \tag{B-2}$$

$$T = \left[I - N\right]^{-1} \tag{B-1}$$

where

I = identity matrix of order equal to the total number of items (raw materials, sub-assemblies and finished products.)

An algorithm is available to compute the inverse of $(I - N)$ matrix (2).

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$$T_i = \sum_{k=i+1}^{m} n_{ki} \ T_k + I_i \tag{B-2}$$

where

T_i = ith column vector of matrix T.

m = total number of parts (raw materials, sub-assemblies and finished products).

n_{ki} = element in the kth row and ith column of N matrix.

I_i = column of the identity matrix with value of ith element as unity.

The column vectors of matrix T are represented as -

$$T = \left[T_1, T_2 \text{ ---------- } T_m\right] \tag{B-3}$$

The value of vector T_m is known, because T is a lower triangular matrix. The values of other vectors of T matrix are computed by moving backwards from vector m to the first vector and by using the recurrence relationship as indicated in equation (B-2).

The computer program listing for Plug and Chug method has been included in Appendix D. The program, written in FORTRAN IV is capable of handling upto 50 different items for each finished product. This restriction can be easily relaxed for bigger problems by modifying the DIMENSION statement in the program. Before using the program the item numbers are renumbered so as to make the input data matrix N, a lower triangular matrix, as was explained earlier. The program provides the results in the form of printed report and punched cards. This punched deck output represents the elements of total requirements matrix T for the final product. These punched cards are useful as input data for other computer programs.

References :

1. Vazsonyi, A., Scientific Programming in Business and Industry, John Wiley and Sons, Inc., New York, 1958, Chapter 13.

2. Mize, J.H., C.R. White and G.H. Brooks, Operations Planning and Control, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1971.

3. Elmaghraby, S.E., "A Note on Explosion and Netting Problems in the Planning of Materials Requirements", Operations Research, Vol. 11, 1963, pp. 530-535.

4. Curado, Fernando and H.P. Hassel, "A Simplified Computational Procedure for the Gozinto Problem," Unpublished Research Memorandam, School of Industrial Engineering, Purdue University, March 1967.

5. "Plug and Chug Technique for Explosion Problems," Lecture Notes for course ME 579, School of Industrial Engineering, Purdue University, 1969.

APPENDIX C

COMPUTER PROGRAM LISTING

```
**** ********** ****
FORECASTING PROGRAM
**** **************

C        [illegible] *************************************************
C
C ***    [illegible] ****************************************************
C ***    [illegible] FORECASTER FORMAT [illegible]
C
C        [illegible] CYCLE [illegible] FOR [illegible]
C ***    [illegible] PARAMETERS -
C        [illegible] PERIODS
C        ID(J) [illegible] I PERIOD J
C
C ***    [illegible] VARIABLES -
C        [illegible] - [illegible] FOR PERIOD I.
C        [illegible] - [illegible] FORECASTING FOR PERIOD I.
C        [illegible] - [illegible] ERRORS FOR FORECASTED FOR [illegible] I.
C        [illegible] - [illegible] FORECASTING.
C        [illegible] - [illegible] PERIOD.
C        [illegible] - [illegible] ABSOLUTE ERROR IN FORECASTING.
C        [illegible] - [illegible] OF PERIODS IN THE CYCLE [illegible].
C        [illegible] - [illegible] PERIODS [illegible] CYCLE.
C        [illegible] - [illegible] DEVIATION.
C        [illegible] DEMANDS ID(J)
C
C ***    [illegible] *
C        [illegible]
C
C        ****************************************************************
C
      [illegible] ( ),JU( ),IERR( ), ( , ), ( , ), [illegible]
      [illegible]
      [illegible] )
      [illegible] (ID(J),J= ,N)
  [illegible] ( , )
      [illegible]
  [illegible] (/////// ,*TOTAL NO. OF PAST DEMAND PERIODS = *,I.////
      [illegible] =
      [illegible]
```

```
      NM1=NM+1
C *** FOLLOWING LOOP CALCULATES THE OPTIMUM NO. OF PERIODS IN EACH CYCLE
C     FOR MINIMUM TOTAL ABSOLUTE ERROR IN FORECASTING.
      DO 20 NN=2,N
      DO 20 MM=2,N
      IF (NN.EQ.MM) GO TO 20
      DO 19 LL=2,N
      IF (LL.EQ.NN) GO TO 19
      IF (LL.EQ.MM) GO TO 19
C ***    CALL FORCS SUBROUTINE TO CALCULATE TOTAL ABSOLUTE ERROR IN
C        FORECASTING.
      CALL FORCS(N,ID,JD,IERR,IERAB,A,IDTOT,JDTOT,IERTOT,AA,BB,C,D,E,IABT
     1 TOT,H,NN,F,G,MM,LL,J,NM,NM1)
C
C     STORE MINIMUM VALUE OF TOTAL ERROR IN FORECASTING AND NO. OF
C     PERIODS.
C
      IF (MINABT.EQ.0) GO TO 10
       IF (MINABT-IABTOT) 20,1 ,10
   10 MINABT=IABTOT
      NNOPT=NN
      MMOPT=MM
      LLOPT=LL
   19 CONTINUE
   20 CONTINUE
C ***    CALL FORCS SUBROUTINE TO GENERATE FORECASTING PARAMETERS FOR
C        MINIMUM TOTAL ABSOLUTE ERROR IN FORECASTING.
      CALL FORCS(N,ID,JD,IERR,IERAB,A,IDTOT,JDTOT,IERTOT,AA,BB,C,D,E,MIN
     1ABT,H,NNOPT,F,G,MMOPT,LLOPT,U,NM,NM1)
       PRINT 112,NNOPT,MMOPT,LLOPT
  112 FORMAT (////8X,80(1H*)////8X,*NO. OF PERIODS PER CYCLE (NN) = *,I8
     1////8X,*NO. OF PERIODS PER CYCLE (MM) = *,I8////8X,*NO. OF PERIODS
     2 PER CYCLE (LL) = *,I8////8X,80(1H*)/////)
       PRINT 102,AA,BB,C,D,E,F,G,H,U
  102 FORMAT (//8X,41H****  THIS IS THE DEMAND FORECASTER  ****////5X,63
     1HD(T)=A+B*T+C*T**2+D*COS(PI*T/E)+F*COS(PI*T/G)+H*COS(PI*T/U)+VAR//
     2//8X,*A = *,E18.8,5X,*B = *,
     3E18.8,5X,*C = *,E18.8,5X,*D = *,E18.8/8X,*E = *,E18.8,5X,*F = *,E1
     48.8,5X,*G = *,E18.8,5X,*H = *,E18.8/8X,*U= *,E18.8//)
       PRINT 103,(I,ID(I),JD(I),IERR(I),IERAB(I),I=1,N)
  103 FORMAT (//8X,48H***THIS IS DEMAND FOR PRESENT 'N' PERIODS *****///
     1/8X,*PERIOD ACTUAL CALCULATED ERROR IN ABSOLUTE ERROR*/15X,*DEMAND
     2   DEMAND    FORECAST IN FORECAST*////(4X,5I8//))
       PRINT 104,IDTOT,JDTOT,IERTOT,MINABT
  104 FORMAT (//8X,*TOTAL ACTUAL DEMAND = *,I8////8X,*TOTAL FORECASTED
     1DEMAND = *,I8////8X,*TOTAL ERROR IN FORECASTING = *,I8////8X,*TOTA
     2L ABSOLUTE ERROR IN FORECASTING = *,I8//)
C
C     *************************************************************************
C
C     THIS CALCULATES THE MINIMUM VALUE OF STANDARD DEVIATION.
C
C     *************************************************************************
C
      IERTOT=IERR(1)
```

```
      IER2=IERR(1)**2
      IER2T=IER2
      DO 60 I=2,N
      IER2=IERR(I)**2
      IER2T=IER2T+IER2
      IERTOT=IERTOT+IERR(I)
      ISUM2=IERTOT**2
      N1=I-1
      PSIG=FLOAT((I*IER2T-ISUM2)/(I*N1))
      SIGMA=SQRT(PSIG)
      IF (I.LE.6) GO TO 60
      QSIG=FLOAT(IER2T/(I-NM))
      SIGMA1=SQRT(QSIG)
      SIGMA=AMIN1(SIGMA,SIGMA1)
   60 CONTINUE
      PRINT 120,SIGMA
  120 FORMAT (3X,*AK = *,E18.8)
      PUNCH 121,AA,BB,C,D,E,F,G,H,U,SIGMA
  121 FORMAT (8X,F16.6)
C
C     ******************************************************************
C
C     THIS IS FORECAST FOR NEXT N PERIODS
C
C     ******************************************************************
C
      N2=N*2
      DO 50 I=N,N2
      AI=I
   50 JD(I)=AA+BB*AI+C*AI**2+D*COS((22.*AI)/(7.*E))+.5+F*COS((22.*AI)/(7
     1.*G))+H*COS((22.*AI)/(7.*U))
      PRINT 105,(I,JD(I),I=N,N2)
  105 FORMAT (//3X,48H****THIS IS FORECAST FOR FUTURE 'N' PERIODS****
     1////8X,*PERIOD FORECAST*//(4X,2I8//))
      STOP
      END




       SUBROUTINE FORCS(N,ID,JD,IERR,IERAB,A,IDTOT,JDTOT,IERTOT,AA,BB,C,
      1D,E,IABTOT,H,NN,F,G,MM,LL,U,NM,NM1)

       ********************************************************************

  *** THIS IS SUBROUTINE FORCS *******************************************
  *** PURPOSE - TO DETERMINE MINIMUM ABSOLUTE ERROR IN FORECASTING.

       ********************************************************************

       DIMENSION ID(100),JD(100),IERR(100),A(10,10),B(10,10),IERAB(100)
```

```
      E=FNN/2.
      G=FLOAT(M1)/2.
      U=FLOAT(LL)/2.
      IDTOT=0
      DO 1 J=1,N
    1 IDTOT=IDTOT+ID(J)
      DTOT=IDTOT
      DN=N
      DAVG=DTOT/DN
      DO 7 L=1,NM1
      DO 7 M=1,NM1
    7 A(L,M)=0.

      REDEFINE D AND T BY AK AND H TO DECREASE NO. OF CALCULATIONS
      DAVG= AVERAGE ACTUAL DEMAND IN N PERIODS
      AK=D-DAVG
      T=J=PERIOD
      H=T-N/2

      DO 2 J=1,N
      D=ID(J)
      AK=D-DAVG
      T=J
      H=T-DN/2.
      CO=COS((2[illegible].*T)/(7.*E))
      CO2=COS(([illegible].*T)/(7.*G))
      CO3=COS(([illegible].*T)/(7.*U))
      A(2,1)=A(2,1)+AK
      A(2,3)=A(2,3)+H
      A(2,4)=A(2,4)+H*H
      A(3,1)=A(3,1)+H*AK
      A(3,4)=A(3,4)+H**3
      A(4,1)=A(4,1)+H*H*AK
      A(4,4)=A(4,4)+H**4
      A(4,5)=A(4,5)+H*H*CO
      A(2,5)=A(2,5)+CO
      A(3,5)=A(3,5)+H*CO
      A(5,5)=A(5,5)+CO*CO
      A(2,6)=A(2,6)+CO2
      A(3,6)=A(3,6)+H*CO2
      A(4,6)=A(4,6)+H*H*CO2
      A(5,6)=A(5,6)+CO*CO2
      A(6,1)=A(6,1)+AK*CO2
      A(6,6)=A(6,6)+CO2*CO2
      A(2,7)=A(2,7)+CO3
      A(3,7)=A(3,7)+H*CO3
      A(4,7)=A(4,7)+H*H*CO3
      A(5,7)=A(5,7)+CO*CO3
      A(6,7)=A(6,7)+CO2*CO3
      A(7,7)=A(7,7)+CO3*CO3
      A(7,1)=A(7,1)+AK*CO3
    2 A(5,1)=A(5,1)+AK*CO
      A(2,2)=DN
      A(3,3)=A(2,4)
```

```
      I=K
    3 I=I+1
      A(I,K)=A(K,I)
      IF (I-NM1) 3,4,4
    4 CONTINUE

      ************************************************************************

      DETERMINANT OF ORDER NM BY PIVOTAL CONDENSATION METHOD

      ************************************************************************

      DO 35 II=1,NM
      DO 6 J=1,NM
      DO 6 K=1,NM
      J1=J+1
      K1=K
      IF (K.GE.II)K1=K1+1
    6 B(J,K)=A(J1,K1)
      K=2
      L=1
      DETERM=1.
      M=0
    5 DO 10  I=K,NM
   11 IF (ABS(B(L,L)).LE.1.0E-25) GO TO 8
      GO TO 12
    8 M=M+1
      DO 9 KM=L,NM
      LM=L+M
      B(KM,L)=B(KM,LM)
      B(KM,LM)=B(KM,L)
    9 DETERM=-DETERM
      GO TO 11
   12 RATIO=B(I,L)/B(L,L)
      DO 10 J=K,NM
   10 B(I,J)=B(I,J)-B(L,J)*RATIO
      IF (K-NM) 15,20,20
   15 L=K
      K=K+1
      GO TO 5
   20 DO 25 L=1,NM
   25 DETERM=DETERM*B(L,L)
      GO TO (30,31,32,33,34,36,37),II
   30 B1=DETERM
   31 C1=DETERM
   32 D1=DETERM
   33 E1=DETERM
   34 F1=DETERM
   36 D2=DETERM
   37 F2=DETERM
   35 CONTINUE
      F=D2/2.
      AA=(C1+D1*F+E1*F**2)/B1+DAVG
      BB=(-D1-2.*E1*F)/B1
```

```
      D=-F1/B1
      F=01/B1
       H=-F2/B1
      JDTOT=0
      IERTOT=0
      IABTOT=
      DO 40 I=1,4
      AI=I
      JD(I)=AA+BB*AI+C*AI**2+D*COS((22.*AI)/(7.*E))+.5+F*COS((22.*AI)/(7
     1.*G))+H*COS((22.*AI)/(7.*U))
      IERR(I)=JD(I)-ID(I)
      IERAB(I)=IABS(IERR(I))
      IABTOT=IABTOT+IERAB(I)
      JDTOT=JDTOT+JD(I)
   40 IERTOT=IERTOT+IERR(I)
      RETURN
      END
```

****

PL[illegible] PROGR[illegible]

****

```
*****************************************************************************
****[illegible] FOR[illegible]AST T[illegible] [illegible]ATES OF PRODUCTION QUANTITIES
****[illegible]
****[illegible] SOLUTI[illegible] USING PLUG [illegible] CHUG METHOD
**
** [illegible] PARAMETERS -
   [illegible] ( GIVEN RAW MATERIAL,PURCHASED PART OR SUB-[illegible]
   [illegible]( , )= [illegible] USED DIRECTLY TO MAKE ONE UNIT OF ASSEMBLY J
   [illegible]( , )= ( , )= [illegible]( ,J) I[illegible] J.GT.[illegible]
*****[illegible] M[illegible]RIX
**
*** [illegible] VARIABLES -
   T( ,J)=[illegible] REQUIREMENT OF PARTS I BY PART J FOR SUB-ASSEMBLY OR F
          [illegible]Y
   T( ,J)= [illegible] J=[illegible] ( ,J)= IF J.GT.[illegible]
****[illegible] MATRI[illegible]
**
*****************************************************************************

   I[illegible] T
   [illegible]( , U),T( C, J)
   [illegible] / [illegible] * /
   [illegible]
   D[illegible]
 [illegible]0 R[illegible] C , ,J,[illegible]J
   I[illegible] ( .L . ) [illegible]
   [illegible]( ,J)= J
   [illegible]
 [illegible] C[illegible]
   [illegible],( , = , )
   [illegible]( I,( ( ,J),J= , ),I= , )
   [illegible] K= ,
   [illegible] I= ,
   T( ,K)=
   IF (I-K) , ,
 [illegible]0 T( ,K)= ( ,K)+[illegible]
 [illegible]0 CONTINUE
   [illegible] = [illegible]-
   T( , )=[illegible]( , )*T( , )
   D[illegible] K= , [illegible]
```

```
      = -
      =   +
            I=   ,
            J=   ,
    T(  ,  )=  (J,   )*T(  ,J)+T(I,  )
    C
    C
    C
            ,(  ,  ,  )
            ,(  ,(  (I,J),J=  ,  ),I=  ,  )
          I=  ,
            ,(  ,  )
      (////    ,  ( H*),*TOTAL NO. OF PARTS = *,I  ////  ,  (  *),*
      ...  AT I (GIVEN)*///)
    F  (  ,  )
    F  (///  ,  I  //))
    F  (///    ,    )
    F  (  )
    F  (I  )
    F  (////   ,  ( H*),*  IS   F  MATRIX OF PARTS REQUIRED*///)
```

****

SIMULATOR   PROGRAM

****

```
C *** THIS IS MAIN PROGRAM ********************************************
C  ** PRODUCTION SYSTEM SIMULATOR - FOR A TV INDUSTRY
C
C  ** DESCRIPTION OF INPUT PARAMETERS -
C         I50 - NUMBER OF STOCK NUMBERS.
C         J50 - NUMBER OF WORK STATIONS.
C         J40 - MAXIMUM NUMBER OF COMPONENTS PERMITTED PER SN.
C         LQ - QUEUE LENGTH (SAME FOR ALL WORK STATIONS).
C         NT - NUMBER OF FINISHED GOODS.
C         NOO - NUMBER OF ALLOWED OUTSTANDING PURCHASE ORDERS.
C         ISP - NUMBER OF SUBPERIODS.
C         IROW - NUMBER OF EXPECTED COMPUTER RUNS.
C         IP - RANDOM NUMBER GENERATOR SEED VALUE FOR ESTIMATING LEAD
C              TIME
C         IX - RANDOM NUMBER GENERATOR SEED VALUE FOR ESTIMATING DEMAND.
C         PST(I,J,K) - AN ARRAY CONTAINING PROCESS TIME,SET UP TIME,HOLD
C                      QUANTITY AND WORK STATION ORDER.
C              I = STOCK NUMBER.
C              J = WORK STATION NUMBER.
C              K = A CODE THAT INDICATES TYPE OF INFORMATION.
C              IF K = 1 - PROCESS TIME IN MINUTES.
C                 K = 2 - SET UP TIME IN MINUTES.
C                 K = 3 - HOLD QUANTITY IN LOTS.
C                 K = 4 - WORK STATION ORDER (THIS NUMBER INDICATES THE
C                         POSITION OF WORK STATION J IN THE NETWORK
C                         SEQUENCE OF STOCK NUMBER I).
C         RMR(I,J,K) - AN ARRAY CONTAINING COMPONENT REQUIREMENTS DURING
C                      MANUFACTURING - STOCK NUMBER OF COMPONENT,QUANTIT
C                      OF COMPONENT, AND WORK STATION AT WHICH THE
C                      COMPONENT ENTERS THE MANUFACTURING PROCESS.
C              I = STOCK NUMBER OF ITEM BEING MANUFACTURED.
C              J = A NUMBER FROM 1 TO J40. THE VALUE OF J(1,2,3,---)
C                  INDICATES THE SEQUENCE IN WHICH A COMPONENT ENTERS TH
C                  PROCESS.
C              K = A CODE THAT INDICATES THE TYPE OF INFORMATION.
C              IF K = 1 - STOCK NUMBER OF COMPONENT ENTERING THE PROCESS
C                 K = 2 - QUANTITY OF COMPONENT (IN UNITS) REQUIRED TO
C                         PRODUCE ONE UNIT OF STOCK NUMBER I.
C                 K = 3 - WORK STATION NUMBER AT WHICH THE COMPONENT
C                         ENTERS THE MANUFACTURING PROCESS.
C         OHR(I,J) - AN ARRAY CONTAINING MONETARY RATES IN RUPEES PER
C                    MINUTE FOR MEN AND MACHINES.
C              I = WORK STATION NUMBER.
C              J = A CODE THAT INDICATES THE TYPE OF INFORMATION.
C              IF J = 1 - MAN RATE ON FIRST SHIFT.
```

```
C               J = 2 - MAN RATE ON SECOND SHIFT.
C               J = 3 - MAN RATE ON THIRD SHIFT.
C               J = 4 - MAN RATE ON OVERTIME.
C               J = 5 - MACHINE RATE WORKING.
C               J = 6 - MACHINE RATE IDLE.
C        VOH - VARIABLE OVERHEAD AS A FRACTION OF TOTAL LABOR COST.
C        OH - FIXED OVERHEAD IN RUPEES.
C        SC - SHIFT CHANGE COST.
C        FTAB(I,J) - AN ARRAY CONTAINING ALL INVENTORY DATA FOR EACH
C                    STOCK NUMBER IN THE SYSTEM.
C             I = STOCK NUMBER.
C             J = A CODE THAT INDICATES THE TYPE OF INFORMATION
C             IF J = 1 - A CODE = 1 - STOCK NUMBER I IS A PURCHASED ITEM
C                                 2 - STOCK NUMBER I IS A MANUFACTURED
C                                     ITEM.
C               J = 2 - LOT SIZE IN UNITS.
C               J = 3 - CARRYING COST PER UNIT PER WEEK.
C              *J = 4 - REORDER COST PER ORDER.
C               J = 5 - STOCK ON HAND IN UNITS.
C               J = 6 - COST PER UNIT.
C               J = 7 - ISSUES THIS WEEK.
C               J = 8 - RECEIPTS THIS WEEK.
C              *J = 9 - DISCOUNT ORDER QUANTITY IN UNITS.
C              *J = 10 - REGULAR PRICE PER UNIT.
C              *J = 11 - DISCOUNT PRICE PER UNIT.
C              *J = 12 - AVERAGE LEAD TIME IN WEEKS.
C              *J = 13 - STANDARD DEVIATION OF LEAD TIME IN WEEKS.
C             **J = 14 - OUT OF STOCK COST PER UNIT PER WEEK.
C              *J = 15 - STOCK ON ORDER IN UNITS.
C               J = 16 - CARRYING COST THIS WEEK.
C             **J = 17 - NUMBER OF UNITS BACKORDERED.
C             **J = 18 - OUT OF STOCK COST THIS WEEK.
C             **J = 19 - BATCH SIZE IN UNITS.
C          *APPLIES ONLY TO PURCHASED ITEMS.
C         **APPLIES ONLY TO MANUFACTURED ITEMS.
C        US - NUMBER OF MINUTES PER SHIFT PER SUBPERIODS.
C        A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),U(I),AK(I) - THESE
C               ARRAYS CONTAIN PARAMETERS FOR DEMAND GENERATOR FOR
C               FINISHED GOODS (PUNCHED OUTPUT OF FORECASTER PROGRAM).
C             I = STOCK NUMBER OF THE FINISHED GOOD.
C        PINVTY - MAXIMUM ALLOWABLE INVENTORY IN RUPEES.
C        VINVP - PENALTY FACTOR FOR EXCESS INVENTORY.
C        NMS(I) - AN ARRAY CONTAINING THE NUMBER OF SHIFT-MINUTES PER
C                 SUBPERIOD THAT WS I WAS OPERATING AT THE END OF THE
C                 LAST PERIOD OF SIMULATION.
C             I = WORK STATION NUMBER.
C        NWS - NUMBER OF WEEKS OF SIMULATION.
C        TINC - TIME INCREMENT IN MINUTES.
C        GPNO - USERS SIMULATION RUN SERIAL NUMBER.
C        ITP - INITIAL TIME PERIOD IN MINUTES.
C        IIS - SWITCH TO PUNCH INITIAL INVENTORY STATUS.
C        ACUNCO - ACTUAL UNIT COST OF FINISHED PRODUCT.
C        ACINVN - ACTUAL INVENTORY COST PER PERIOD (AVERAGE).
C        BL - A BLANK.
C        DOT - A PERIOD.
```

```
C        PLT - PLOT CHARACTERS TO BE PUNCHED IN COLUMNS 3 THRU 7 ARE
C              RESPECTIVELY,THE LETTER F,THE LETTER U,THE LETTER I, AN
C              ASTERISK AND THE LETTER X.
C
C  ** DESCRIPTION OF VARIABLES -
C        VOI - INITIAL TOTAL INVENTORY VALUE IN RUPEES.
C        IFTP - LAST TIME PERIOD IN MINUTES.
C        SUMRY(I,J) - SUMMARY OF FINAL RESULTS.
C          I = NUMBER OF SIMULATION PERIOD.
C          J = A CODE THAT INDICATES THE TYPE OF INFORMATION.
C          IF J = 1 - FORECAST FOR FINAL PRODUCT.
C             J = 2 - ACTUAL DEMAND FOR FINAL PRODUCT.
C             J = 3 - CALCULATED UNIT COST OF FINAL PRODUCT.
C             J = 4 - ACTUAL     UNIT COST OF FINAL PRODUCT.
C             J = 5 - CALCULATED INVENTORY COST.
C             J = 6 - ACTUAL     INVENTORY COST.
C             J = 7 - WEEKLY PRODUCTION TIME.
C             J = 8 - INVENTORY ORDERING COST.
C             J = 9 - CURRENT INVENTORY CARRYING COST.
C             J = 10 - CUMULATIVE OUT OF STOCK COST.
C             J = 11 - WEEKLY TOTAL PLANT COST.
C             J = 12 - CUMULATIVE PLANT COST.
C             J = 13 - CURRENT INVENTORY VALUE.
C             J = 14 - CUMULATIVE PENALTY ASSESSMENT.
C             J = 15 - CUMULATIVE COST OF OPERATION.
C        IOTNMS - TOTAL NUMBER OF SHIFT-MINUTES PER DAY OF ALL WORK
C                 STATIONS.
C        TOTNMS - TOTAL NUMBER OF SHIFT-MINUTES AVAILABLE EACH WEEK TO
C                 THE SYSTEM.
C
C  ** OTHER ROUTINES USED -
C      **MAPA**     **FORCST**     **PRODTN**       **INVENT**
C
C    THE FOLLOWING SET OF INSTRUCTIONS REPRESENT THE FORTRAN SOURCE PROGRA
C    WHICH IS USED FOR INITIALIZING THE DATA SETS. ITS REFERENCE NAME IS
C    PROSGO
C
      DIMENSION NMS(15),A(3),B(3),C(3),D(3),E(3),F(3),G(3),H(3),U(3),
     1AK(3),PST(59,15,4),RMR(59,5,3),OHR(15,6),HD(3),FTAB(59,19)
     2,W(3),SER(3),ABE(3),APPLY(59),FTAB8(59),ORDER(200,3),Q(15,20,3),
     3HOLD(15,4),MW(15,4),OHRP(59),OHRM(59),ALT(200),COST(59),FCST(3),
     4SUTCT(15),TA(15),IOT(15),OM(5),IDLE(15),OMI(15),OHJ(15),OMJ(15),
     5IDIC(5),SK(5),INTCT(15),MS(15),SUMRY(50,15),MIOT(15),MTA(15),
     6ERR(3),RMC1(59),P(50,100),PLT(5),T(50,5)
      COMMON /CLCJR/ O,ITP,IX,TINC,HRT,OC,SPNLT,US,CMU,CMC,KTP,IP,VOH,
     1PINVTY,SC,OH,AIDL,CUM,SSC,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
      COMMON /PROSIM/ RMC1,NMS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,MW,
     1OHRP,OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,W,SUTCT,TA,
     2IOT,OM,IDLE,OMI,OHJ,OMJ,IDIC,SK,INTCT,MS,ISP,MIOT,MTA
      INTEGER OM,SK,PN,QT,TM,PNU,HQ,T,HOLD,SN,Q,SUT,TEMP1,TEMP2,TA,US
      INTEGER PST,RMR
      INTEGER RUN,TINC,ORDER,GPNO
      INTEGER P,BL,DOT,PLT
      DATA SUMRY/750*0./
      DATA O,HRT,OC,SPNLT,CMU,CMC,VOH,PINVTY,SC,OH,AIDL,CUM,SSC,TDI,TDM,
```

```
     1VINVP,DUM,ITP,IX,TINC,US,IP,IFTP,IDL,ITTA,N,I50,J50,J40,KTP/17*0.,
     213*0/
      DATA PST,RMR,Q,ORDER,HOLD,MW,NMS,FTAB,OHR,APPLY,FTAB8,RMC1,OHRP,
     1OHRM,A,B,C,D,E,F,G,H,U,AK,SER,ABE/2515*0, 780*0./
C     THIS INPUTS THE NUMBER OF STOCK NUMBERS, THE NUMBER OF WORK
C     STATIONS, THE MAXIMUM NUMBER OF COMPONENTS PER STOCK NUMBER,
C     THE MAXIMUM QUEUE LENGTH, THE NUMBER OF DIFFERENT FINISHED GOODS,
C     THE MAXIMUM PERMITTED NUMBER OF OUTSTANDING PURCHASE ORDERS,
C     THE NUMBER OF WORKDAYS PER WEEK,THE NUMBER OF PLANNED WEEKS OF
C     SIMULATION AND TWO SEED NUMBERS FOR RANDOM NUMBER GENERATION
      READ(5,158) I50,J50,J40,LQ,NT,NOO,ISP,IROW,IP,IX
  158 FORMAT (8I5,2I10)
C     READ INITIAL TIME PERIOD
      READ(5,124) ITP,IIS
  124 FORMAT (2I5)
      IFTP=ITP-1
C     THIS READS ALL THE VALUES FOR THE VARIOUS DATA ARRAYS AND
C     CONSTANTS USED IN OPERATING THE SIMULATOR. IC IS A CODE WHICH IS
C     USED TO DETERMINE WHICH TYPE OF DATA HAS BEEN PUNCHED INTO A DATA
C     CARD. I, J AND M RESPECTIVELY REPRESENT THE ROW, COLUMN AND PLANE
C     SUBSCRIPTS OF THE MEMORY CELL INTO WHICH A DATA VALUE IS TO BE
C     STORED (IF THE ITEM IS NOT PART OF AN ARRAY, THESE ARE LEFT BLANK)
C     CH IS THE DATA VALUE WHICH IS BEING STORED.
  106 READ(5,127) IC,I,J,M,CH
  127 FORMAT (4I2,F16.6)
      IF (IC.LE.0) GO TO 108
  107 IF (IC.EQ.1) PST(I,J,M)=CH
      IF (IC.EQ.2) RMR(I,J,M)=CH
      IF (IC.EQ.3) OHR(I,J)=CH
      IF (IC.EQ.4) VOH=CH
      IF (IC.EQ.5) OH=CH
      IF (IC.EQ.6) SC=CH
      IF (IC.EQ.7) FTAB(I,J)=CH
      IF (IC.EQ.8) US=CH
      CC=CH
      IND=IC
      IF (IND.EQ.11) A(I)=CC
      IF (IND.EQ.12) B(I)=CC
      IF (IND.EQ.13) C(I)=CC
      IF (IND.EQ.14) D(I)=CC
      IF (IND.EQ.15) E(I)=CC
      IF (IND.EQ.16) F(I)=CC
      IF (IND.EQ.17) G(I)=CC
      IF (IND.EQ.18) H(I)=CC
      IF (IND.EQ.19) U(I)=CC
      IF (IND.EQ.20) AK(I)=CC
      IF (IND.EQ.21) PINVTY=CC
      IF (IND.EQ.22) VINVP=CC
      IF (IC.EQ.15.AND.CC.LE.0.)E(I)=1
      IF (IC.EQ.19.AND.CC.LE.0.)U(I)=1
      IF (IC.EQ.17.AND.CC.LE.0.)G(I)=1
      GO TO 106
      WRITE (6,22)
      WRITE (6,23)PINVTY
      WRITE (6,24) VINVP
```

```
      WRITE (6,25) OH
      WRITE (6,26) VOH
      WRITE (6,27) SC
   22 FORMAT (*0*,40X,*STARTING PARAMETERS*/41X,19(1H*))
   23 FORMAT (*0*,30X,*INVENTORY LIMIT =*,F11.2)
   24 FORMAT (*0*,30X,*INVENTORY PENALTY =*,F7.3,*  TIMES EXCESS INVENTO
     1RY*)
   25 FORMAT (*0*,30X,*FIXED OVERHEAD =*,F10.2)
   26 FORMAT (*0*,30X,*VARIABLE OVERHEAD =*,F7.3,*  TIMES DIRECT LABOR*)
   27 FORMAT (*0*,30X,*SHIFT CHANGE COST =*,F8.2)
  108 CONTINUE
C ***      CALL MAPA PROGRAM - TO GENERATE INVENTORY PARAMETERS.
      CALL MAPA (PST,FTAB,I50,J50,US,ISP)
C     THIS INPUTS THE NUMBER OF MINUTES PER DAY EACH WORK STATION WAS
C     OPERATING DURING THE *PREVIOUS WEEK*. EVEN THOUGH, IN REALITY,
C     THERE WAS NO WEEK PREVIOUS TO THE FIRST ONE TO BE SIMULATED BY THE
C     USER, A VALUE USUALLY 480) IS NECESSARY SO THAT SHIFT CHANGE COSTS
C     CAN BE CALCULATED SHOULD THE USER DECIDE TO OPERATE TWO OR THREE
C     SHIFTS ON HIS INITIAL RUN
  115 READ (5,162) (NMS(J),J=1,J50)
  162 FORMAT (5I13)
C     THE NEXT FOUR WRITE STATEMENTS GENERATE THE HEADINGS FOR AND PRINT
C     THE INITIAL STATUS (CARRYING COST, REORDER COST, QUANTITY ON HAND,
C     UNIT COST, DISCOUNT ORDER QUANTITY, REGULAR ORDER PRICE, DISCOUNT
C     ORDER PRICE, AVERAGE LEAD TIME AND BACKORDER COST) OF EACH ITEM IN
C     INVENTORY.
      WRITE (6,500)
  500 FORMAT (1H0,50X,*INITIAL INVENTORY STATUS*)
      WRITE (6,501)
  501 FORMAT (1H ,7X,*STOCK*,5X,*CARRYING*,6X,*REORDER*,7X,*STOCK*,9X,
     1*UNIT*,6X,*DISCOUNT*,6X,*REGULAR*,5X,*DISCOUNT*,6X,*AVERAGE*,5X,
     2*BACKORDER*)
      WRITE (6,502)
  502 FORMAT (1H ,6X,*NUMBER*,7X,*COST*,9X,*COST*,8X,*ON HAND*,8X,*COST*
     1,2X,*ORDER QUANTITY  ORDER PRICE*,2X,*ORDER PRICE*,3X,*LEAD TIME*,6
     2,6X,*COST*,/)
      DO 100 I=1,I50
      IF (FTAB(I,3).LE.0.) GO TO 100
      WRITE (6,504) I,FTAB(I,3),FTAB(I,4),FTAB(I,5),FTAB(I,6),FTAB(I,9),
     1FTAB(I,10),FTAB(I,11),FTAB(I,12),FTAB(I,14)
  504 FORMAT (1H ,I11,F14.5,F13.2,F13.0,F13.4,F13.0,2F13.4,F13.2,F13.4)
C     THIS SERVES AS A SWITCH TO PERMIT OR NOT PERMIT THE PUNCHING OF
C     THE INITIAL INVENTORY STATUS. SUCH PUNCHED OUTPUT MAY BE USEFUL.
      IF (IIS.LE.0) GO TO 100
      WRITE (7,329) I,FTAB(I,3),FTAB(I,4),FTAB(I,5),FTAB(I,6),FTAB(I,9),
     1FTAB(I,10),FTAB(I,11),FTAB(I,12),FTAB(I,14)
  329 FORMAT (I3,2X,F8.5,F8.2,2X,F8.0,1X,F8.4,F8.0,2F8.4,F8.2,F8.4)
  100 CONTINUE
 1001 VOI=0
C     THIS CALCULATES THE INITIAL INVENTORY VALUE (TOTAL).
      DO 117 M=1,I50
  117 VOI=VOI+FTAB(M,5)*FTAB(M,6)
      WRITE (6,156) VOI
  156 FORMAT (1H0,42X,*CURRENT TOTAL VALUE OF INVENTORY*,13X,F10.2)
      WRITE (6,295)
```

```
C     THE FOLLOWING SET OF INSTRUCTIONS REPRESENT THE FORTRAN SOURCE
C     PROGRAM WHICH IS USED FOR THE PRODUCTION SIMULATIONS. ITS
C     REFERENCE NAME IS PROSIM.
C
      READ (5,123) NWS,TINC,GPNO
  123 FORMAT (3I5)
      WRITE (6,41) IP,IX
   41 FORMAT (1H0,5X,*THE VALUES OF SEED FOR THIS SIMULATION RUN ARE AS
     1FOLLOWS*///10X,*SEED FOR GENERATING LEAD TIME =*,I10//10X,*SEED
     2FOR GENERATING ACTUAL DEMAND =*,I10//)
      DO 105 KKK=1,NWS
C     CALL FORECAST PROGRAM
      CALL FORCST (RMC1,NMS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,MW,OHRP,
     1OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I50,J50,J40,W,NOO
     2,LQ,NT,ISP,FCST,ERR)
C     CALL PRODUCTION PROGRAM
      CALL PRODTN(I50,J50,J40,LQ,NOO,NT)
C ***     CALL INVENTORY PROGRAM.
      CALL INVENT(RMC1,NMS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,MW,OHRP,
     1OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I50,J50,J40,W,
     2NOO,LQ,NT,ISP,SUMRY,IROW,FCST)
  105 CONTINUE
      WRITE(6,296)
  296 FORMAT(1H0,*SIMULATION COMPLETE*)
      DO 1111 M=1,I50
      IF (FTAB(M,1).LE.0.) GO TO 1111
      WRITE (7,171) GPNO,M,FTAB(M,5),FTAB(M,15)
 171  FORMAT (2I5,2F10.0)
 1111 CONTINUE
C
C     THE FOLLOWING SET OF INSTRUCTIONS REPRESENT THE FORTRAN SOURCE
C     PROGRAM WHICH IS USED FOR LISTING THE USER SUMMARY TABLES.
C     IT S REFERENCE NAME IS LSTTBL.
C
C     THIS READS ACTUAL UNIT COST OF FINAL PRODUCT AND ACTUAL INVENTORY
C     COST (AVERAGE).
      READ (5,50) ACUNCO,ACINVN
   50 FORMAT (2F10.0)
      DO 60 I=1,NWS
      SUMRY(I,4)=ACUNCO
      SUMRY(I,6)=ACINVN
   60 CONTINUE
C     PRINT SUMMARY TABLE.
      WRITE (6,42)
   42 FORMAT(1H1,4X,*FCST*,2X,*ACT*,3X,*CALC*,4X,*ACT*,5X,*CALC*,6X,*ACT
     1*,4X,*TOTAL*,5X,*INV*,5X,*INV*,4X,*OUT OF*,4X,*PLANT*,6X,*PLANT*)
      WRITE(6,43)
   43 FORMAT(1H ,4X,*UNIT*,1X,*UNIT*,3X,*UNIT*,3X,*UNIT*,5X,*INVN*,5X,
     1*INVN*,4X,*PRODN*,3X,*ORDER*,3X,*CARRY*,4X,*STOCK*,6X,*COST*,7X,
     2*COST*,3X,*INVENTORY*,3X,*TOTAL*)
      WRITE(6,44)
   44 FORMAT(1H ,5X,*ONE*,2X,*ONE*,3X,*COST*,3X,*COST*,5X,*COST*,5X,
     1*COST*,5X,*TIME*,4X,*COST*,4X,*COST*,5X,*COST*,7X,*PER*,8X,*CUM*,
```

```
   45 FORMAT(1H0,I3,2F5.0,2F7.3,2F9.2,F9.0,3F8.3,3F11.2,F8.2,F12.2)
      IOTNMS=0
C     TOTAL MINUTES AVAILABLE IN THE SYSTEM PER DAY.
      DO 80 I=1,J50
      IOTNMS=IOTNMS+NMS(I)
   80 CONTINUE
C     TOTAL MINUTES AVAILABLE PER WEEK.
      TOTNMS=IOTNMS*ISP
C     READ PLOT CHARACTERS.
      READ (5,40) BL,DOT,PLT
   40 FORMAT (7A1)
      DO 73 K=1,NWS
      DO 76 J=1,5
   76 T(K,J)=0.
C     ABSOLUTE DIFFERENCES BETWEEN THE FORECASTED AND ACTUAL VALUES FO
C     FINAL PRODUCT IS ENLARGED ON PLOT.
      T(K,1)=(ABS(SUMRY(K,1)-SUMRY(K,2))*6.)+.5
C     PERCENTAGE IMPROVEMENT IN UNIT COST OF FINAL PRODUCT IS ENLARGED
      T(K,2)=ABS(SUMRY(K,3)-SUMRY(K,4))*250./SUMRY(K,4)+.5
C     PERCENTAGE IMPROVEMENT IN TOTAL INVENTORY COST OVER ACTUAL
C     INVENTORY COST.
      T(K,3)=ABS(SUMRY(K,5)-SUMRY(K,6))*100./SUMRY(K,6)+.5
C     MINUTES OF PRODUCTION AND OPERATING COST ARE SCALED TO FIT INTO
C     PLOT AREA.
      T(K,4)=SUMRY(K,7)* 50./TOTNMS+.5
      T(K,5)=SUMRY(K,11)/600.+.5
   73 CONTINUE
C     THESE LOOPS DETERMINE THE POSITION FOR AND INSERT PLOT CHARACTER
C     INTO THE PLOT ARRAY IN MEMORY.
      DO 77 JJ=1,5
C     THE NEXT SEVEN STATEMENTS CLEAR THE PLOT ARRAY AND THEN INSERT
C     DOTS FOR THE X AND Y AXIS.
      DO 70 K=1,50
      DO 70 J=1,100
   70 P(K,J)=BL
      DO 71 K=1,50
      DO 71 J=3,100,8
   71 P(K,J)=DOT
      DO 72 J=1,100
   72 P(50,J)=DOT
      DO 78 M=1,NWS
      L=M*2
      K=51-T(M,JJ)
      IF(K.LE.0.OR.K.GT.50)GC TO 78
      P(K,L)=PLT(JJ)
      LP=L+1
      P(K,LP)=PLT(JJ)
   78 CONTINUE
      WRITE (6,46)(I,I=1,50,2)
   46 FORMAT (1H1,10X,*GRAPHICAL REPRESENTATION OF RESULTS*/11X,35(1H
     115X,25I4/)
      DO 79 K=1,50
      JK=50-K
```

```
   47 FORMAT (1H ,1 X,I5,2X,10 A1)
   79 CONTINUE
      WRITE(6,48)(J,J=1,50,2)
   48 FORMAT(1H ,14X,25I4//40X,*NO. OF WEEKS ---------*)
      GO TO (40 ,401,402,403,4 4),JJ
  400 WRITE(6,141)
  141 FORMAT (1H0,17X,*PLOT CHARACTER F REPRESENT ABSOLUTE DIFFERENCE
     1BETWEEN FORECAST AND ACTUAL FOR FINAL PRODUCT*/18X,*VERTICAL SCAL
     2 IS  6 DOTS = 1 UNIT OR ONE INCH = 1 UNIT*//50X,*FIG. - 11*)
      GO TO 77
  401 WRITE (6,144)
  144 FORMAT (1H0,17X,*PLOT OF PERCENTAGE IMPROVEMENT IN UNIT COST OF
     1FINAL PRODUCT*/18X,*VERTICAL SCALE IS ONE DOT = 0.4 PERCENT OR ON
     2 INCH = 2.4 PERCENT*)
      GO TO 77
  402 WRITE (6,145)
  145 FORMAT (1H0,17X,*PLOT OF PERCENTAGE IMPROVEMENT IN TOTAL INVENTOR
     1 COST OVER ACTUAL INV. COST*/18X,*VERTICAL SCALE IS ONE DOT = 1.C
     2PERCENT OR ONE INCH = 6 PERCENT*)
      GO TO 77
  403 WRITE(6,142)
  142 FORMAT (1H0,17X,*PLOT OF PERCENTAGE UTILISATION OF PRODUCTION CAP
     1CITY*/18X,*VERTICAL SCALE IS ONE DOT = 2 PERCENT OR ONE INCH = 12
     2PERCENT*)
      GO TO 77
  404 WRITE(6,143)
  143 FORMAT(1H0,17X,*PLOT OF PLANT OPERATING COST. VERTICAL SCALE IS (
     1E INCH =RS3600 OR ONE DOT =RS600*)
   77 CONTINUE
      STOP
      END




C
C *** THIS IS SUBROUTINE MAPA ****************************************
C *** PURPOSE - TO CALCULATE INVENTORY PARAMETERS.
C
C *** DESCRIPTION OF INPUT PARAMETERS -
C         FDOQ - FACTOR OF DISCOUNT ORDER QUANTITY.
C         IR - UNIT REQUIREMENT FOR MANUFACTURING FINAL ITEM (REARRANGE
C              - PUNCHED OUTPUT OF EXPLOSION PROGRAM).
C
C *** DESCRIPTION OF VARIABLES -
C         LPT - LONGEST PROCESS TIME IN MINUTES.
C         EPC - ESTIMATED PLANT CAPACITY IN PIECES PER WEEK.
C         R - WEEKLY USAGE RATE.
C         EOQ - ECONOMIC ORDER QUANTITY IN NUMBER OF PIECES.
```

```
      DIMENSION PST( 29,  6,4),FTAB( 29,19)
      INTEGER PST,EPC,US
      LPT=0
C     CALCULATE LONGEST PROCESS TIME IN ASSEMBLY LINE.
      DO 20 I=1,I50
      DO 20 J=1,J50
      IF (LPT-PST(I,J,1)) 10,2 ,20
   10 LPT=PST(I,J,1)
   20 CONTINUE
      WRITE (6,100) LPT
C     CALCULATE ESTIMATED PLANT CAPACITY IN PIECES PER WEEK.
      EPC=US*ISP/LPT
      READ (5,200) FDOQ
      WRITE (6,110) EPC,FDOQ
      WRITE (6,120)
      CALCULATE DISCOUNT ORDER QUANTITY FOR EACH PURCHASED ITEM (FTAB(I,
      DO 30 I=2,I50
      READ (5,210) IR
      IF (FTAB(I,1).EQ.2.) GC TO 30
      R=IR*EPC
      SEOQ=2.*R*FTAB(I,4)/FTAB(I,3)
      EOQ=SQRT(SEOQ)
      FTAB(I,9)=FDOQ*EOQ
      WRITE (6,130) I,IR,R,ECQ,FTAB(I,9)
   30 CONTINUE
  100 FORMAT(1H1,5(/),30X,*LONGEST PROCESS TIME =*,I6,5X,*MINUTES*////)
  110 FORMAT(1H ,20X,*ESTIMATED PLANT CAPACITY =*,I8,5X,*PIECES PER WEEK
     1*////20X,*FACTOR OF DOQ =*,F10.4///)
  120 FORMAT(1H0,7X,*STOCK*,7X,*UNIT*,7X,*WEEKLY*,7X,*ECONOMIC ORDER*,5X
     1,*DISCOUNT ORDER*/6X,*NUMBER*,3X,*REQUIREMENT*,2X,*USAGE RATE*,7X,
     2*QUANTITY*,9X,*QUANTITY*//)
  130 FORMAT(/7X,I5,3X,I8,F13.1,6X,F13.1,6X,F13.1)
  200 FORMAT(F10.4)
  210 FORMAT(I5)
      RETURN
      END

C
C *** THIS IS SUBROUTINE FORCST ****************************************
C *** PURPOSE - TO GENERATE DEMAND OF FINAL PRODUCT AND TO COMPARE IT
C                COMPARE IT WITH ACTUAL DEMAND.
C
C *** DESCRIPTION OF INPUT PARAMETER -
C          FCST(K) - USERS FORECAST FOR THIS PERIOD FOR FINAL PRODUCT -
C                    ACTUAL SALES DATA FROM PAST DEMAND HISTORY.
C              K = STOCK NUMBER OF FINISHED PRODUCT.
```

```
C
      SUBROUTINE MAPA(PST,FTAB,I50,J50,US,ISP)
      DIMENSION PST( 29,  8,4),FTAB( 29,19)
      INTEGER PST,EPC,US
      LPT=0
C     CALCULATE LONGEST PROCESS TIME IN ASSEMBLY LINE.
      DO 20 I=1,I50
      DO 20 J=1,J50
      IF (LPT-PST(I,J,1)) 10,20,20
   10 LPT=PST(I,J,1)
   20 CONTINUE
      WRITE (6,100) LPT
C     CALCULATE ESTIMATED PLANT CAPACITY IN PIECES PER WEEK.
      EPC=US*ISP/LPT
      READ (5,200) FDOQ
      WRITE (6,110) EPC,FDOQ
      WRITE (6,120)
      CALCULATE DISCOUNT ORDER QUANTITY FOR EACH PURCHASED ITEM (FTAB
      DO 30 I=2,I50
      READ (5,210) IR
      IF (FTAB(I,1).EQ.2.) GO TO 30
      R=IR*EPC
      SEOQ=2.*R*FTAB(I,4)/FTAB(I,3)
      EOQ=SQRT(SEOQ)
      FTAB(I,9)=FDOQ*EOQ
      WRITE (6,130) I,IR,R,EOQ,FTAB(I,9)
   30 CONTINUE
  100 FORMAT(1H1,5(/),30X,*LONGEST PROCESS TIME =*,I6,5X,*MINUTES*///
  110 FORMAT(1H0,20X,*ESTIMATED PLANT CAPACITY =*,I8,5X,*PIECES PER W
     1*////20X,*FACTOR OF DOQ =*,F10.4///)
  120 FORMAT(1H0,7X,*STOCK*,7X,*UNIT*,7X,*WEEKLY*,7X,*ECONOMIC ORDER*
     1,*DISCOUNT ORDER*/6X,*NUMBER*,3X,*REQUIREMENT*,2X,*USAGE RATE*,
     2*QUANTITY*,9X,*QUANTITY*//)
  130 FORMAT(/7X,I5,3X,I8,F13.1,6X,F13.1,6X,F13.1)
  200 FORMAT(F10.4)
  210 FORMAT(I5)
      RETURN
      END
```

```
C
C *** THIS IS SUBROUTINE FORCST ************************************
C *** PURPOSE - TO GENERATE DEMAND OF FINAL PRODUCT AND TO COMPARE IT
C                COMPARE IT WITH ACTUAL DEMAND.
C
C *** DESCRIPTION OF INPUT PARAMETER -
C        FCST(K) - USERS FORECAST FOR THIS PERIOD FOR FINAL PRODUCT -
C                    ACTUAL SALES DATA FROM PAST DEMAND HISTORY.
C                K = STOCK NUMBER OF FINISHED PRODUCT.
```

```
C
C *** DESCRIPTION OF VARIABLES -
C         W(K) - CALCULATED DEMAND VALUE OF ITEM K.
C         ERR(K) - ERROR IN FORECASTING FOR ITEM K.
C         SER(K) - SUM OF ERRCR IN FORECASTING (CUMULATIVE).
C         ABE(K) - SUM OF ABSOLUTE ERROR IN FORECASTING (CUMULATIVE).
C         SALES - OUTSIDE SALES (IF ANY).
C         NVAS - STOCK NUMBER OF RAW MATERIAL FIRST IN NETWORK QUEUE.
C         PNO - STOCK NUMBER CF PURCHASED ITEMS FOR WHICH PURCHASE ORD
C               IS PLACED.
C         SIZO - QUANTITY OF ITEM PNO ORDERED IN THIS PERIOD.
C         ORDER(J,K) - ORDER MATRIX FOR PURCHASE ORDERS.
C         J = ORDER NUMBER.
C         K = A CODE THAT INDICATES TYPE 6F INFORMATION.
C         IF K = 1 - STOCK NUMBER OF ITEM ORDERED.
C            K = 2 - QUANTITY ORDERED FOR THE ITEM.
C            K = 3 - TIME PERIOD THIS ORDER WILL ARRIVE.
C         ALT(J) - TIME PERIOC WHEN ORDER WILL ARRIVE.
C         J = ORDER NUMBER.
C         JOC - CUMULATIVE COST OF ORDERING IN CURRENT PERIOD.
C
C *** ROUTINE USED -
C         **RANNUM**
C
      SUBROUTINE FORCST(RMC1,NMS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,
     1OHRP,OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I50,J50,J
     2W,NOO,LQ,NT,ISP,FCST,ERR)
      COMMON /CLCJR/ O,ITP,IX,TINC,HRT,OC,SPNLT,US,CMU,CMC,KTP,IP,VOH
     1PINVTY,SC,OH,AIDL,CUM,SSC,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
      DIMENSION RMC1( 29),NMS(  8),APPLY( 29),FTAB8( 29),FTAB( 29,19)
     1PST( 29,  8,4),RMR( 29,  5,3),OHR(  8,6),Q(  8,20,3),HOLD(  8,4
     2MW(  8,4),OHRP( 29),OHRM( 29),ALT(200),COST( 29),ORDER(200,3),
     3A( 3),B( 3),C( 3),D( 3),E( 3),F( 3),G( 3),H( 3),U( 3),AK( 3),
     4SER( 3),ABE( 3),W( 3),FCST( 3),ERR( 3)
      INTEGER TA,US,PN,QT,TM,PNU,HQ,T,HOLD,SN,Q,SUT,TEMP1,TEMP2
      INTEGER PST,RMR
      INTEGER TINC,ORDER
      DATA TEMP2,TA,PN,QT,TM,PNU,HQ,T,SN,SUT,TEMP1,DUMB/11*0,0./
      DATA NP,SALES,PNO,SIZO/0,3*0./
      DO 50 ICC2=1,NT
   40 FCST(ICC2)=0
   50 ERR(ICC2)=0
C     THE NEXT 6 STATEMENTS WRITE HEADER FOR FORECAST DATA
      WRITE (6,135)
      WRITE (6,136)
      WRITE (6,137)
  117 DO 118 K=1,NT
C     READ USERS FORECASTS
   60 READ (5,138) FCST(K)
      CALL RANNUM(IX,RRAN,RAAN)
      NP=K
      DEV=(-2.*ALOG(RRAN))**0.5*COS(6.283*RAAN)*AK(NP)
      V=ITP
C     CALCULATE DEMAND VALUE FOR CURRENT PERIOD.
        W(K)=A(NP)+B(NP)*V+C(NP)*V**2+D(NP)*COS((3.1416*V)/E(NP))+F(N
```

```
     1COS((3.1416*V)/S(NP))+F(NP)*COS((3.1416*V)/U(NP))+DEV
      IW=W(K)+.5
      W(K)=IW
      ERR(K)=FCST(K)-W(K)
      ABE(K)=ABE(K)+ABS(ERR(K))
      SER(K)=SER(K)+ERR(K)
      WRITE (6,119) K,ITP,W(K),FCST(K),ERR(K),SER(K),ABE(K)
      IF (W(K).LT.0.) W(K)=0
  118 CONTINUE
      XYZ= .
  119 CONTINUE
C     PUT NP=0 IF NO OUTSIDE SALES.
      NP=
      IF (NP.LE. ) GO TO 12
      IF (SALES.GT.FTAB(NP,5)) SALES=FTAB(NP,5)
      FTAB(NP,7)=FTAB(NP,7)+SALES
      FTAB(NP,5)=FTAB(NP,5)-SALES
      XYZ=.
      WRITE (6,  ) NP,SALES
      GO TO 119
  12  CONTINUE
      WRITE (6,  )
      YY=0
C     GENERATE  NEW MATERIAL ORDERS TO MEET CALCULATED DEMAND IN THIS
C     PERIOD.
      KTP=KTP+1
      IK=0
      IJ=1
  204 IF (IK.EQ.J4 ) IJ=IJ+1
      IF (IJ.GT.I5 ) GO TO 209
      IF (IK.EQ.J40) IK=0
      IK=IK+1
      NVAS=RMR(IJ,IK,1)
      IF ((FTAB(NVAS,1).EQ.2.).OR.(NVAS.LE.0)) GO TO 204
      PNO=NVAS
      SIZO=FLOAT(RMR(IJ,IK,2))*W(1)
C     PART NUMBER IS CHECKED TO INSURE IT IS A VALID NUMBER.
      DO 205 II=1,I50
      IF (IFIX(PNO).EQ.II) GO TO 206
  205 CONTINUE
      WRITE (6,   ) PNO
      YY=1
      IF (IJ.GT.I50) GO TO 209
      GO TO 204
  150 WRITE (6,  ) PNO
  300 FORMAT (1H0,5X,*QUANTITY ORDERED FOR SN *,F5.0,* LESS THAN ZERO
     1 ORDER IGNORED*)
      YY=1
      IF (IJ.GT.15 ) GO TO 209
      GO TO 204
  206 IF (FTAB(II,1).EQ.2.) GO TO 2 3
      IF (SIZO.LT. .) GO TO 15
      DO 207 J=1,2
      IF (ORDER(J,1).NE.0) GO TO 207
      CALL RANNUM(IP,RRAN,RAAN)
        S=(-2.*ALOG(RRAN))**0.5*COS(6.283*RAAN)
C     CALCULATE TIME PERIOD (LEAD TIME) WHEN THE ORDER J WILL ARRIVE
      ALT(J)=FTAB(II,  2)+FTAB(II,13)*S+FLOAT(KTP)
```

```
      ORDER(J,2)=SIZE
      ORDER(J,3)=ALT(J)
      FTAB(II,15)=FTAB(II,15)+SIZE
      KK=IFIX(P 1 )
      OC=OC+FTAB(KK, )
      IPNOL=P 1
      ISIZL=SIZE
      WRITE (6, 0 ) IPNOL,ISIZL,J
  301 FORMAT (1H0, X,*ORDER PLACED FOR SN *,I5,* FOR*,I10,* UNITS ...
     1ORDER NO *,I5)
      IF (IJ.GT.I5 ) GO TO 209
      GO TO 204
  207 CONTINUE
      WRITE (6,224) P 0
      YY=
      IF (IJ.GT.I50) GO TO 209
      GO TO 2 4
  2 8 WRITE (6, 5) P 10
      YY=
      IF (IJ.GT.I50) GO TO 209
      GO TO 2 4
  2 9 CONTINUE
      IF (YY.EQ. .) WRITE (6,226)
      ITP=ITP+
  121 CONTINUE
      RETURN
C
  122 FORMAT (  . )
  123 FORMAT (  F . )
  124 FORMAT (I5)
  125 FORMAT (I )
  126 FORMAT (1 ,  ,  )
  127 FORMAT (4I ,F . )
  128 FORMAT (21 ,F  . )
  129 FORMAT (I , X,F .3,F8.2, X,F8.0,1X,F8.4,F8.0,2(F8.4),F8.2,F8.4)
  130 FORMAT (   )
  131 FORMAT (1H , X,  ,*TIME SERIES  */51X,11(1H*))
  132 FORMAT (1H , X,*TIME*,5 )
  133 FORMAT (9 ,I5,6 ,4( 0F7. /10X))
  134 FORMAT (  ,I ,5X,4( 0F7. /10X))
  135 FORMAT (1H ,5 X,*RESULTS OF FORECAST*/51X,19(1H*))
  136 FORMAT (1H , X,*STOCK  *,8X,*TIME*,10X,*ACTUAL*,6X,*FORECAST*,
     120X,*SUM OF*, X,*SUM OF ABSOLUTE*)
  137 FORMAT (1H , X,*NUMBER*,9X,*PERIOD*,8X,*VALUR*,8X,*VALUE*,9X,
     1*ERROR*,8X,*ERROR*,8X,*ERROR*)
  138 FORMAT (F  . )
  139 FORMAT (1H0,10X,14,10X,I5,5X,F10.2,3X,F10.2,6X,F8.2,3X,F10.2,3X,
     1F10.2)
  140 FORMAT (1H ,40X,*ADDITIONAL SALES*)
  141 FORMAT (I ,F  . )
  142 FORMAT (1H0,10X,*STOCK NUMBER*,I5,5X,*SALES OF *,F10.0,* UNITS*)
  143 FORMAT (1H , X,*NO ADDITIONAL SALES*)
  220 FORMAT (1H ,5 X,*PURCHASE ORDERS AND ERRORS*/51X,26(1H*))
  2   FORMAT (2F . )
  224 FORMAT (1H0,5X,*UNABLE TO FILL ORDER FOR STOCK NUMBER*,F6.2,5X,*
     1ORDER BANKS FULL*)
  223 FORMAT (1H ,5X,*STOCK NUMBER*,F6.2,5X,*DOES NOT EXIST*)
  225 FORMAT (1H ,5X,*STOCK NUMBER*,F6.2,*  IS NOT A PURCHASED PART*)
  226 FORMAT (1H0,15X,*ALL REQUESTS PROCESSED*)
      END
```

```
      SUBROUTINE PRODCT(I5 ,J5 ,J4 ,LQ,NOO,NT)
C
C *** THIS IS SUBROUTINE PRODCT ****************************************
C *** PURPOSE - TO SIMULATE ONE WEEK OF PRODUCTION ACTIVITIES AT EACH
C               WORK STATION.
C
C  ** DESCRIPTION OF VARIABLES -
C        Q(I,J,K) - MATRIX CONTAINING INFORMATION CONCERNING THE QUEUES
C                   AT WORK STATIONS.
C          I = WORK STATION UNDER CONSIDERATION.
C          J = QUEUE POSITION UNDER CONSIDERATION.
C          K = A CODE THAT INDICATES TYPE OF INFORMATION.
C          IF K = 1 - STOCK NUMBER OF THE ITEM.
C             K = 2 - QUANTITY IN THE QUEUE.
C             K = 3 - ORDER NUMBER OF THE LOT.
C        W(I,J) - WORK STATION DETAILS.
C          I = WORK STATION UNDER CONSIDERATION.
C          J = A CODE THAT INDICATES TYPE OF INFORMATION.
C          IF J = 1 - STOCK NUMBER OF WORK IN PROGRESS.
C             J = 2 - TIME THE WORK STATION WILL BE THROUGH PROCESSING.
C             J = 3 - ORDER NUMBER OF ITEM UNDER PROCESSING.
C             J = 4 - LOT SIZE OF THE ITEM UNDER PROCESSING.
C        HOLD(I,J) - HOLD BLOCK DETAILS.
C          I = WORK STATION UNDER CONSIDERATION.
C          J = A CODE THAT INDICATES TYPE OF INFORMATION.
C          IF J = 1 - STOCK NUMBER OF ITEM IN HOLD BLOCK.
C             J = 2 - QUANTITY IN HOLD BLOCK.
C             J = 3 - QUANTITY HOLD BLOCK IS TO ACCUMULATE BEFORE
C                     RELEASING GOODS TO THE NEXT WORK STATION OR
C                     INVENTORY.
C             J = 4 - ORDER NUMBER OF ITEM IN HOLD BLOCK.
C        TA(I) - TIME THE WORK STATION I IS TO WORK IN MINUTES PER WEEK.
C        ILT(I) - FORCED OVERTIME THE WORK STATION I IS TO WORK.
C        NS(I) - NUMBER OF SHIFT-MINUTES THE WORK STATION I CAN WORK
C                EACH DAY.
C        HTA(I),HIOT(I) - TEMPORARY DUPLICATE PREPARED FOR TIME
C                         AVAILABLE AND FORCED OVERTIME VALUES FOR WORK
C                         STATION I.
C        ON(K) - WORK STATION NUMBERS AT WHICH A COMPONENT ENTERS THE
C                PROCESS , WHERE K = COMPONENT SEQUENCE NUMBER IN
C                ENTERING AT WORK STATION.
C        SK(I),ITIC() - TEMPORARY ARRAYS CONTAINING THE SN AND QUANTITY
C                       OF COMPONENTS IN SEQUENCE NUMBER K.
C        SUTCT(I) - NUMBER OF SETUPS OF WORK STATION I.
C        RMC1(I) - COST OF RAW MATERIAL I, USED.
C        OHRP(I),OHRM(I) - MAN AND MACHINE COSTS FOR THE APPROPRIATE
C                          SHIFT FOR ITEM I.
C        IDLE(I) - IDLE TIME AT WORK STATION I (TOTAL THIS WEEK).
```

```
C          OMI(I),OMJ(I) - IDLE MACHINE AND MAN COSTS AT WORK STATION I.
C          COST(J) - CUMULATIVE COST OF ORDERING AND PAYMENTS OF THE ORDER
C                    IN RUPEES FOR ITEM J.
C
C    * ROUTINES USED -
C       **WRIT 6**
C
      DIMENSION MMS( ),A(3),B(3),C(3),D(3),E(3),F(3),G(3),H(3),U(3),
     1AK(3),PST(29, 3,4),RMR(29,5,3),OHR( 8,6),        FTAB(29,19)
     2,W(3),SER(3),ABE(3),APPLY(29),FTABB(29),ORDER(200,3),Q( 8,20,3),
     3HOLD( 8,4),MW( ,4),OHRP(29),OHRM(29),ALT(200),COST(29),RMC1(29),
     4SUTCT( ),TA( 5),IOT( 8),OM(5),IDLE( 8),OMI( 8),OHJ( 8),OMJ( 8),
     5IDIC(5),SK(5),INTCT( 8),MS( 8),MIOT( 8),MTA( 8)
      COMMON /CLCJR/ D,ITP,IX,TINC,HRT,OC,SPNLT,US,CMU,CMC,KTP,IP,VOH,
     1PINVTY,SC,OH,AIDL,CUM,SSU,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
      COMMON /PROSIM/ RMC1,MMS,APPLY,FTABB,FTAB,PST,RMR,OHR,Q,HOLD,MW,
     1OHRP,OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,W,SUTCT,TA,
     2IOT,OM,IDLE,OMI,OHJ,OMJ,IDIC,SK,INTCT,MS,ISP,MIOT,MTA
      INTEGER T ,UD,PN,QT,TM,PNU,HQ,T,HOLD,SN,Q,SUT,TEMP1,TEMP2,OM,SK,
     1TEMP ,SUTCT,TINC,ORDER
      INTEGER PUT,RMR
      COMMON /PRODUC/ PN,QT,TM,PNU,HQ,T,SN,SUT,TEMP1,TEMP2,TOC,ISUM,DB
      DATA  PN,QT,TM,PNU,HQ,T,SN,SUT,TEMP1,TEMP2,ISUM,TOC,DB/11*0,2*0./
      DATA   ,UT,KBK,JBH,KBH,TA,ISTRT,IEND,IBY,IDAY,PNU,MNU,HQ/13*0/
      DO 1235   JHM3=1,J5
      TA(JHM3)=
      IOT(JHM3)=0
      IDLE (JHM3)=
      OMI(JHM )=
      OMJ(JHM )=0
      INTCT(JHM3)=0
      MS(JHM3)=
 1235  SUTCT(JHM3)=
      DO   236   JHM3=1,I50
      COST(JHM3)=0.
      OHRP(JHM3)= .
 1236 OHRM(JHM3)= .
      DO   237 JHM3=1,J40
      OM(JHM3)=0
      IDIC(JHM3)=
 1237 SK(JHM3)=
      CUM=0.
      AIDL=0.
      D= .
      HRT= .
      TEMP=0
      LQ =LC-
      WRITE (6,  )
      X=
C     GENERATE PRODUCTION ORDERS FOR CURRENT WEEK TO MEET THE DEMAND OF
C     FINAL PRODUCT.
C     PN - STOCK NUMBER.
C     QT - QUANTITY TO BE PRODUCED.
      PN=
      QT=W(PN)
```

```
      GO TO 99
  102 IF(PN.E ).2) PN=.7
      IF(PN.GT.IN ) GO TO 1.8
      QT=W(1)
   99 IF (PN.LE.)) GO TO 103
C     CHECK FOR NON-EXISTANT PRODUCT NO.
      IF (PN.LT. .OR.PN.GT.I5 ) GO TO 1 4
C     DETERMINE FIRST WS IN NETWORK FOR THE ORDER.
      DO 1C3 I3=1,J60
      MO=PST(PN,I3,-)
      IF (MO. 0..) GO TO 1 5
  1 3 CONTINUE
C     PRODUCT HAS NO INITIAL WS.
      X=1
      WRITE (6,165) PN,QT
      PN=PN+1
      GO TO 102
  1 4 WRITE (6,1 6) PN,QT
      X=1
      PN=PN+1
      GO TO 102
C     SEARCH QUEUE FOR FIRST AVAILABLE EMPTY POSITION.
  1 5 DO   I4= ,LQ
      IF (Q(I ,I4, ).EQ.0) GO TO 107
  106 CONTINUE
      X=1
C     QUEUE OVERFLOW - CAUSES THIS PRODUCTION ORDER TO BE PURGED FROM
C     THE SYSTEM.
      WRITE (6,1 7) PN,QT
      PN=PN+1
      GO TO 1 
C     PLACE ORDER IN PROPER QUEUE IN FIRST AVAILABLE EMPTY POSITION.
  107 Q(I ,I4,1)=PN
      N=N+1
C
C     QUANTITY I  THE QUEUE = QUANTITY TO BE PRODUCED/LOT SIZE.
C
      Q(I ,I4,2)=QT/IFIX(FTAB(PN,2))
      Q(I ,I4,3)=N
      WRITE (6,25) PN,QT
   25 FORMAT (1H , Y,*ORDER PLACED FOR SN*,I4,*  FOR *,I5, * BATCHES*)
      PN=PN+1
      GO TO 1 2
  108 CONTINUE
      IF (X.EQ. .) WRITE (6,17 )
C
C     ALL PROCESSABLE ORDERS PLACED IN INITIAL QUEUES.
C *** GENERATE TIME EACH WORK STATION IS TO WORK.
C
  1 9 CONTINUE
      IF (K4K.L . ) GO TO 111
      TA(K4K)=JBH
      INT(K4K)=KBH
      IF (K4K.LT. .OR.K4K.GT.J50) GO TO 112
C *** TIME ALLOWED IS BROKEN INTO ONE DAY SEGMENTS.
```

```
      TA(K4K)=TI(K4K)/ISP
      IOT(K4K)=IOT(K4K)/ISP
C *** ALL TIMES ARE CHECKED TO INSURE THAT THEY ARE ACCEPTABLE TIME.
      LBH=3*US
      IF (TA(K4K).GT.LBH) GO TO 110
      IF (TA(K4K).EQ.LBH) MS(K4K)=3*US
      IF (TA(K4K).LT.LBH.AND.TA(K4K).GE.(2*US)) MS(K4K)=2*US
      IF (TA(K4K).EQ.(2*US)) MS(K4K)=2*US
      IF (TA(K4K).LT.(2*US).AND.TA(K4K).GE.US) MS(K4K)=US
      IF (TA(K4K).LE.US) MS(K4K)=US
      IF (TA(K4K).LT. US) WRITE (6,171) K4K
      IF (TA(K4K).LT.US) TA(K4K)=US
      GO TO 109
C *** EXECUTED WHEN TIME AVAILABLE VALUE IS GREATER THAN THREE SHIFTS.
  110 WRITE (6,170) K4K
      TA(K4K)=3*US
      MS(K4K)=3*US
      GO TO 109
  111 CONTINUE
      DO 201 LIKE=1,J5
      MTA(LIKE)=TA(LIKE)
      MIOT(LIKE)=IOT(LIKE)
  201 CONTINUE
      GO TO 103
C *** ERROR MESSAGE FOR NON-EXISTANT WORK STATION.
  112 WRITE (6,172) K4K
      X=1
      TA(K4K)=US
      MS(K4K)=US
      GO TO 109
  113 CONTINUE
C *** CHECKING FOR MISSING TIME AVAILABLE DECISIONS. THOSE MISSING ARE
C     ASSIGNED THE VALUE OF ONE SHIFT.
      DO 114 I=1,J5
      IF (TA(I).GT. ) GO TO 11
      IF (OHR(I, ).L . .) GO TO 114
      TA(I)=US
      MTA(I)=US
      MS(I)=US
  114 CONTINUE
C     PRINT OUT ALL TIME AVAILABLES AFTER ANY NECESSARY CHANGES.
      DO 6666 I=1,J5
      IF (TA(I).L . ) GO TO 6666
      WRITE (6,6667) I,TA(I)
 6667 FORMAT (1H0,10X,*TIME AVAILABLE AT WS *,I ,* IS *,I10)
 6666 CONTINUE
C     READ PARAMETERS FOR INTERMEDIATE RESULTS.
      READ (5,174) IM,ISTRT,IEND,IBY,IDAY
C     COMPUTE MAXIMUM TIME AVAILABLE.
      KBH=0
      DO 3166 JBH=1,J5
 3166 IF (TA(JBH).GT.KBH) KBH=TA(JBH)
      TM=KBH
      X=0
C  ** GENERATE HOLD QUANTITY.
```

```
  115 CONTINU
      IF (PNU.L  . ) G  TO 250
      X= .
      WRITE (6,5568 ) PNU,MNU,HQ
 6668 FORMAT (1 H0,1 ,*HOLD QUANTITY FOR STOCK NUMBER *,I5,* AT WORK STA
     1TION *,I5,* CHANGED TO *,I5,* BATCHES*)
      HQ=HQ/IFIX(FT B(PNU,2))
      IF (HQ.LE.0) HQ=1
      IF (HOLD(MNU,  ).EQ.PNU) HOLD(MNU,3)=HQ
      PST(PNU,MNU,3)=HQ
      GO TO 115
  250 CONTINUE
C
C   ** START SIMULATION.
C      JR5 INDEX STEPS THRU THE 5 DAYS OF THE WEEK.
C
      DO 20  JR5=1,ISP
C      LIKE INDEX STEPS THRU TH  WORK STATIONS TO RE-ESTABLISH THE
C      INITIAL TIME VALUES.
      DO 202 LIKE=1,J50
      TA(LIKE)=NTA(LIKE)
      IOT(LIKE)=NIOT(LIKE)
  202 CONTINUE
C      START THE MASTER CLOCK AT A MINUS 'TINC' VALUE BECAUSE A GO TO
C      LOOP IS USED FOR INDEXING THE MASTER CLOCK. ON THE INITIAL PASS,
C      THE NEXT STATEMENT CAUSES THE INITIAL TIME TO BE ZERO.
  116 T=(-TINC)
  117 T=T+TINC
C      JR INDEX STEPS THRU ALL WORK STATIONS TWICE EACH TIME INCREMENT TO
C      PREVENT IDLE  TI   -CALS. THE WORK FLOW NETWORKS ARE NOT IN WORK
C      STATION SEQUENCE.
      DO 1 4 JR= ,
      DO  4  I= ,J
      KKKG=
      SUT=0
C      CHECKS TO S   IF WORK STATION I HAS REACHED ITS FINISH TIME.
      IF (T.GT.TA(I)) GO TO 14
C      IF PROCESSING  OT FINISH D, IT GOES TO CHECK THE NEXT WORK STATION
      IF (MW(I,3).GT.1) GO TC  44
C      IF TRUE, WORK STATION IS IDLE AND IT IS TIME TO LOOK FOR A
C      PRODUCT TO PROC SS. THIS IS DONE AT STATEMENT 13 .
      IF (MW(I,3).N  .T) GO TC  3
C      REACHING THIS DENOTES COMPLETION OF A PROCESSING AT THIS WORK
C      STATION. IF THIS IS THE FIRST CHECK AT THIS TIME INCREMENT, THE
C      NEXT SEVERAL STATEMENTS ARE USED TO MOVE THE PRODUCT OFF THE WORK
C      STATION. IF THIS IS THE SECOND CHECK, THE PRODUCT WAS MOVED
C      EARLIER AND IT IS TIME TO LOOK FOR A PRODUCT TO PROCESS.
      IF (JR.EQ.2) GO TO 13
      IF (HOLD(I,1).EQ. .AND.MW(I,4).EQ. ) GO TO 13
      IF (HOLD(I,1).EQ.0) GO TO 123
      IF (HOLD(I,1).N .MW(I,1)) GO TO 123
      IF (HOLD(I,4).NE.MW(I,3)) GO TO 123
      IF (MW(I,3).EQ. .AND.MW(I,4).EQ.0) GO TO 130
      HOLD(I,2)=HOLD(1,2)+1
      MW(I,4)=0
```

```
      MW(I,1)=0
C     CHECKS TO SEE IF PRODUCT IN HOLD BLOCK IS READY TO BE MOVED.
  118 IF (HOLD(I,2).LT.HOLD(I,.)) GO TO 130
      I5=HOLD(I, )
      IMO=PST(I ,1, )
      IMO=IMO+.
      DO 119 I6=.,J..
C  ** DETERMINE NEXT WORK STATION IN SEQUENCE.
      MO=PST(I5,I6, )
      IF (MO.EQ.IMO) GO TO 120
  119 CONTINUE
C     REACHING THIS POINT DENOTES THAT PROCESSING ON THIS STOCK NUMBER
C     HAS BEEN COMPLETED AND THE PRODUCT IS MOVED TO INVENTORY.
      FTAB(I5,8)=FTAB(I5,8)+FLOAT(HOLD(I,2))*FTAB(I5,2)*FTAB(I5,19)
      FTAB(I5,5)=FTAB(I5,5)+FLOAT(HOLD(I,2))*FTAB(I5,2)*FTAB(I5,19)
C     ZEROS THE HOLD BLOCK AFTER THE PRODUCT IS MOVED TO INVENTORY.
      HOLD(I,1)=
      HOLD(I,2)=0
      HOLD(I,3)=
      HOLD(I,4)=
      GO TO 130
  120 DO 121 I7=.,LQ
C  ** QUEUES ARE SEARCHED UNTIL ONE IS FOUND WITH THE SAME SN AND ORDER
C  ** NO AS THE ONE IN THE HOLD BLOCK OR UNTIL AN EMPTY QUEUE POSITION
C  ** IS FOUND.
      IF (Q(I6,I7,3). Q.HOLD(I,4).AND.Q(I6,I7,1).EQ.HOLD(I,1)) GO TO 122
      IF (Q(I6,I7,.). Q. ) GO TO 122
  121 CONTINUE
      GO TO 129
  122 CONTINUE
      IF (HOLD(I,1)... ) GO TO 3
C  ** HOLD QUANTITY FROM PREVIOUS WORK STATION IS ADDED TO APPROPRIATE
C  ** QUEUE POSITION OF THE NEXT WORK STATION'S QUEUE.
      Q(I6,I7,.)=HOLD(I,.)
      Q(I6,I7,2)=Q(I6,I7,2)+HOLD(I,2)
      Q(I6,I7,3)=HOLD(I,4)
C     ZERO HOLD BLOCK AT THE PREVIOUS WORK STATION.
  300 HOLD(I,1)=0
      HOLD(I,2)=
      HOLD(I,3)=
      HOLD(I,4)=0
      GO TO 130
C     THIS SECTION DETERMINES THE NEXT WS IN THE NETWORK,IF THERE IS ONE
  123 CONTINUE
      IF (HOLD(I,4)..0.0) GO TO 128
      IF (HOLD(I,.)..0.0) GO TO 128
      I8=HOLD(I,1)
      IMO=PST(I8,I,4)
      IMO=IMO+.
C     THE DO LOOP SEARCHES FOR THE NEXT WS.
      DO 124 I9=.,J5
      MO=PST(I8,I9,4)
      IF (MO.EQ.IMO) GO TO 125
  124 CONTINUE
C     SINCE THERE IS NO NEXT WS,ADD THE COMPLETED PRODUCT TO INVENTORY.
```

```
      FTAB(I8,?)=FT.B(I?,?)+FLOAT(HOLD(I,2))*FTAB(I8,2)*FTAB(I5,19)
      FTAB(I8,5)=FTAB(I8,5)+FLOAT(HOLD(I,2))*FTAB(I8,2)*FTAB(I5,19)
      GO TO 1.8
  125 DO 126 I20=1,L?
C  ** QUEUES AR  S ARCHED UNTIL ONE IS FOUND WITH THE SAME SN AND ORDER
C  ** NO AS THE ONE IN THE HOLD BLOCK OR UNTIL AN EMPTY QUEUE POSITION
C  ** IS FOUND.
      IF (Q(I9,I20, ).EQ.HOLD(I,4).AND.Q(I9,I20,1).EQ.HOLD(I,1)) GO TO
     1127
      IF (Q(I9,I  ,1).EQ.  ) GO TO 127
  126 CONTINUE
      GO TO 129
  127 CONTINUE
C     MOVE THE PRODUCT FROM THE HOLD BLOCK TO THE APPRUPRIATE QUEUE.IF
C     THE ORDER NO IN THE HOLD BLOCK IS ALREADY ZERO,THE PRODUCT IN THE
C     HOLD BLOCK HAS PREVIOUSLY BEEN MOVED.
      IF (HOLD(I,4).EQ. ) GO TO 128
C     PRODUCT HAS NOT BEEN MOVED.THIS IS ACCOMPLISHED BY THE NEXT THREE
C     STATEMENTS.
      Q(I9,I20,1)=HOLD(I,1)
      Q(I9,I2 ,2)=Q(I9,I2 ,2)+HOLD(I,2)
      Q(I9,I2 ,3)=HOLD(I,4)
  128 CONTINUE
C     HOLD BLOCK IS Z RO D.
      HOLD(I,1)=
      HOLD(I, )=
      HOLD(I, )=
      HOLD(I,4)=0
C  .  DETERMI  S WH THER THERE IS A PRODUCT AT THE WORK STATION.
      IF (MW(I,1).  .  .   MW(I,4).EQ. ) GO TO 130
C     NEXT SEVEN ST  EMENTS MOVE THE PRODUCT FROM WS TO THE HOLD BLOCK
C     AND ZERO THE APPROPPIATE ITEMS CONCERNING THE WORK STATION.
      HOLD(I,1)=MW(I,1)
      HOLD(I,?)=HOLD(?,?)+
      I  =MW(I,1)
      HOLD(I,?)=PST(I  ,I,?)
      HOLD(I,4)=MW(I, )
      MW(I,4)=
      MW(I,?)=0
C     THIS CH CKS T  S E IF TH  HOLD BLOCK IS READY TO MOVE.
      GO TO 128
C  ** IF A QUEU  IS NOT AVAILABLE AT THE NEXT WS,ONE TIME INCREMENT IS
C  ** ADDED TO THE FINISH TIME OF WS THAT IS ASSOCIATED WITH THE HOLD
C  ** BLOCK (FULL HOLD BLOCK).
  129 MW(I,?)=MW(I, )+TIMC
      KKKS=
      GO TO 1?
C     THIS SECTION S ARCHES TH  QUEUE POSITIONS FOR SOMETHING TO WORK ON.
  130 CONTINUE
      DO 136 J=1,LQ
      I22=Q(I,J, )
C     IF THE FIRST QU UE POSITION IS EMPTY,GO TO 139,WHICH MOVES ORDERS
C     UP ONE POSITION IN THE QUEUE.
      IF (J.EQ. .AND.I22.EQ.0) GO TO 139
C     CHECKING FOR ZERO STOCK NUMBER.
```

```
      IF (I[illegible]) GO TO [illegible]
C     IF TH[illegible] POSITION IS EMPTY,INDEX ORDERS IN THE QUEUE.
      IF (Q(I,J,[illegible]).L[illegible]) GO TO 139
      IF (Q(I,J,[illegible]).L[illegible]) GO TO 139
      D[illegible] K=[illegible],J4
  131 OM(K)=RMR(I[illegible],K,[illegible])
      I24=0
      DO [illegible] I24=[illegible],J4
      SK(I24)=[illegible]
  [illegible]05 IDIC(I24)=0
C  ** THIS SECTION IS CONCERNED WITH RAW MATERIAL AVAILABILITY.
  [illegible] I24=I24+1
C  ** RAW MATERIAL REQUIREMENTS ARE DETERMINED.
      IF (I24.GT.J40) GO TO 13
      IF (OM(I24).N[illegible].1) GO TO [illegible]32
      SK(I24)=RMR(I[illegible]2,I24,1)
      IDIC(I24)=RMR(I22,I24,2)
      SN=SK(I24)
C     CHECKS INVENTORY TO DETERMINE IF A SUFFICIENT QUANTITY OF ALL RAW
C     MATERIALS IS AVAILABLE.IF A SUFFICIENT QUANTITY DOES NOT EXIST,IT
C     GOES TO STATEMENT [illegible]36 TO CHECK THE PRODUCT IN THE NEXT QUEUE
C     POSITION.
      IF (FTAB(SN,5).LT.(FLOAT(IDIC(I24))*FTAB(I22,2))) GO TO 136
C     CAUSES A RETURN TO CHECK THE NEXT COMPONENT.
      GO TO [illegible]
C     REACHING THIS POINT DENOTES THAT SUFFICIENT QUANTITIES OF ALL RAW
C     MATERIALS EXIST.IT IS NOW POSSIBLE TO PRODUCE THIS PRODUCT.ONE LOT
C     [illegible] TH[illegible] WS AND PRODUCTION STARTS.
  [illegible] CONTINUE
C  ** D[illegible] SET UP TIME.
      SUT=[illegible](I[illegible],I,[illegible])
      IF ([illegible](I,J,[illegible]).[illegible].MW(I,[illegible])) SUT=[illegible]
C     THIS [illegible] TH[illegible] NUMBER OF SETUPS.
      IF (Q(I,J,[illegible]).[illegible].MW(I,[illegible])) SUTCT(I)=SUTCT(I)+1
      [illegible]
      IF ([illegible]).[illegible].1) GO TO [illegible]34
      [illegible]=SK([illegible])
C  ** U[illegible] INV[illegible]TORY (STOCK ON HAND AND ISSUES).
      FTAB(SN,5)=FTAB(SN,5)-FLOAT(IDIC(I25))*FTAB(I22,2)
      FTAB(SN,7)=FTAB(SN,7)+FLOAT(IDIC(I25))*FTAB(I22,2)
C  ** D[illegible] COST OF RAW MATERIALS USED.
      RMC[illegible](I2[illegible])=RMC[illegible](I22)+FLOAT(IDIC(I25))*FTAB(I22,2)*FTAB(SN,6)
      IF (FTAB([illegible]).[illegible]Q.2.) GO TO 134
      C[illegible]=C[illegible]+FLOAT(IDIC(I25))*FTAB(I22,2)*FTAB(SN,6)
  134 CONTINUE
C     TH[illegible] PRODUCT IS MOVED FROM THE QUEUE TO THE WORK STATION.
      MW(I,[illegible])=I2[illegible]
      MW(I,[illegible])=Q(I,J,[illegible])
C     THIS CALCULATES THE NEXT FINISH TIME.
      MW(I,[illegible])=T+SUT+PST(I22,I,[illegible])*IFIX(FTAB(I22,2))
      Q(I,J,2)=Q(I,J,2)-[illegible]
C     THIS DETERMINES IF THE FIRST QUEUE POSITION IS EMPTY.
      IF (Q(I,J,[illegible]).LE.0.AND.J.EQ.1) GO TO 724
      GO TO 725
  7[illegible]4 CONTINUE
```

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      DO   ·  I.6= ,LO.
C   ** I  A S QU UES  FT R FIRST QUEUE HAS BEEN FOUND EMPTY.
      I 7=I26+
      (I,I 6, )=Q(I,I 7,1)
      Q(I,I 6, )=Q(I,I27,3)
   14 Q(I,I 6, )=Q(I,I27, )
      Q(I,  , )=
      Q(I, , )=
      Q(I,  , )=
  7 5 CONTINU
C     THIS LOADS ON  LUT ONTC THE WORK STATION.
      MW(I,4)=
C   ** D T RMIN  WHAT SHIFT THE PLANT IS WORKING.
      IF (T.L .( *US)) L=3
      IF (T.LT.( *US).AND.T.GT.(2*US)) L=4
      IF (T.L .( *US)) L=
      IF (T.LT.( *US).AND.T.GT.US) L=4
      IF (T.L .US) L=
      IF (T.GT. S(I)) L=
C   ** D T RMI  THE MAN AND MACHINE COSTS.
      OHR (  )=OHRP(I22)+FLCAT(MW(I,2)-T)*OHR(I,L)
      OHR (I22)=OHR (I22)+FLCAT(MW(I,2)-T)*OHR(I,5)
C     STAT MENTS FROM HERE TC  39 ARE USED TO PLACE THE PRODUCT IN THE
C     FIRST QUEU  POSITION IF IT WAS NOT ALREADY THERE.
      IF (Q(I,J, ).NE. ) GO TO 135
      Q(I,J,1)=0
      Q(I,J, )=
  135 IF (J.EQ. ) GO TO 144
      T MP =Q(I,J, )
      T MP2=Q(I,J, )
      T MP =Q(I,J, )
      GO TC 137
  136 CONTINU
      GO TO 14
  137 CONTINU
      DO 13  L= ,J
      IF (L.EQ.J) GO TO 138
      IMD=J-L
      IFK=J-L+
      Q(I,IFK, )=Q(I,IMD,1)
      Q(I,IFK,2)=Q(I,IMD,2)
      Q(I,IFK,3)=Q(I,IMD,3)
  138 CONTINUE
      Q(I,1,1)=TEMP
      Q(I,1,2)=TEMP2
      Q(I,1,3)=TEMP3
      IF (Q(I,1, ).GT. ) GO TO 144
      DO  4 I 6=1,LO
      I27=I26+1
      Q(I,I 6, )=Q(I,I 7, )
      Q(I,I 6, )=Q(I,I27,3)
   14 Q(I,I 6, )=Q(I,I27,2)
      Q(I,  , )=
      Q(I,  , )=
      Q(I,  , )=
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```
      GO TO 144
C     IF THE FIRST QUEUE POSITION HAPPENS TO BE EMPTY ALL PRODUCTS ARE
C     SHIFTED FORWARD ONE POSITION.
  139 CONTINUE
      IF (Q(I,2,1).LE. ) GO TO 141
      DO 140 I26=1,LQ
C     THIS IDLE... QUEUES AFTER THE FIRST QUEUE POSITION HAS BEEN FOUND
C     EMPTY.
      I27=I26+1
      Q(I,I26,1)=Q(I,I27,1)
      Q(I,I26,3)=Q(I,I27,3)
  140 Q(I,I26,2)=Q(I,I27,2)
      Q(I,2 ,1)=
      Q(I,2 ,2)=
      Q(I,20,3)=0
      GO TO 13
C     ARRIVAL AT THIS POINT DENOTES THAT THERE IS NOTHING FOR THE
C     SUBJECT WORK STATION TO WORK ON. IT IS THEREFORE NECESSARY TO
C     DETERMINE WHETHER THE WORK STATION SHOULD GO IDLE OR SHUT DOWN.
C     THIS IS THE FUNCTION OF THE STATEMENTS HERE THROUGH STATEMENT 143.
  141 IF (T.GT.MS(I).AND.T.GT.IDT(I)) GO TO 143
      IF (KKKS.EQ.1) GO TO 142
      IF (JR.EQ.1) GO TO 144
C     THIS CALCULATES IDLE TIME AND IDLE COSTS.
  142 CONTINUE
      IF (T.GE.TA(I).OR.(T.GE.MS(I).AND.T.GE.IDT(I))) GO TO 143
      IF (T.L .(3*US)) L=3
      IF (T.LT.(3*US).AND.T.GT.(2*US)) L=4
      IF (T.L .(2*US)) L=3
      IF (T.LT.( *US).AND.T.GT.US) L=4
      IF (T.L .US) L=1
      IF (T.GT.MS(I)) L=4
      IDL (I)=IDL (I)+1
      OMI(I)=OMI(I)+OHR(I,6)
      OHJ(I)=OHJ(I)+OHR(I,L)
      KKKS=
      GO TO 144
  143 TA(I)=T
  144 CONTINUE
      KKKK=
C     THIS DETERMINES WHETHER TO PRINT OUT INTERMEDIATE RESULTS.
      IF (ISTRT.LT. ) GO TO 145
      IF (IDAY.LT.0) GO TO 3335
      IF (JR5.N .IDAY) GO TO 145
 3335 CONTINUE
      DO  45 I MNOT=ISTRT,IEND,IBY
      IF (T.N .IMNOT) GO TO 4444
      ITDUM=T
C     THIS PRINTS INTERMEDIATE RESULTS OF PRODUCTION STATUS.
      CALL WRIT 6 (RMC , MS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,MW,OHRP,
     1OHR ,ALT,COST,       ORDER,A,B,C,D,E,F,G,H,U,AK,SER,A3E,I50,J50,J40,
     2W,NOD,LQ, IT,SUTCT,TA,ICT,OM,IDLE,OMI,OHJ,JMJ,IDIC,SK,INTCT,MS,ISP,
     3ITDUM)
 4444 CONTINUE
  145 CONTINUE
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C      THIS CHECKS TO SEE IF A WORK DAY HAS BEEN COMPLETED.
  146 IF (I.L .EM) GO TO 147
      KKKK=1
C      THIS LOOP CALCULATES THE NEW FINISH TIMES FOR ANY PRODUCTS
C      REMAINING AT ANY WORK STATION,
      DO 148 I=1,J5)
      IF (MW(I,4).EQ. ) GO TC 147
      MW(I, )=MW(I,2)-TA(I)
      GO TO 148
  147 CONTINUE
C      IF NOTHING REMAINS AT A WORK STATION, THE FINISH TIME IS SET TO -1
C      TO CAUSE A SEARCH FOR WORK TO BE INITIATED AT THE BEGINNING OF THE
C                              NEXT WORK DAY.
      MW(I,2)=-
  148 CONTINUE
      LNT=NT+1
      DO 302 L=LNT,150
C   ** UPDATE INVENTORY BY SUBTRACTING BACK-ORDERS.
      FTAB(L,5)=FTAB(L,5)-FTAB(L,17)
      IF (FTAB(L,5).LT.0.) FTAB(L,17)=-FTAB(L,5)
      IF (FTAB(L,5).GE.0.) FTAB(L,17)=0.
      IF (FTAB(L,5).LT.0.) FTAB(L,5)=0
      FTAB(L,18)=FTAB(L,18)+FTAB(L,17)*FTAB(L,14)*(1./FLOAT(ISP))
      FTAB(L,16)=FTAB(L,16)+FTAB(L,3 )*FTAB(L,5 )*(1./FLOAT(ISP))
  302 CONTINUE
      DO 301 I=1,NT
C   ** UPDATE INVENTORY BY SUBTRACTING 1/6 OF WEEKLY DEMAND.
  305 FTAB(I,5)=FTAB(I,5)-FTAB(I,17)
      FTAB(I,5)=FTAB(I,5)-(1./FLOAT(ISP))*W(I)
C   ** COMPUTE CARRYING COSTS FOR THE WEEK.
      FTAB(I,7)=FTAB(I,7)+(1./FLOAT(ISP))*W(I)
      IBH=ABS(FTAB(I,5)-.5)
      IF (FTAB(I,5).LT.0.) WRITE(6,198)  I,IBH,JR5
      IF (FTAB(I,5).LT.0.) FTAB(I,17)=-FTAB(I,5)
      IF (FTAB(I,5).GE.0.) FTAB(I,17)=0.
      IF (FTAB(I,5).LT.0.) FTAB(I,5)=0
      FTAB(I,18)=FTAB(I,18)+FTAB(I,17)*FTAB(I,14)*(1./FLOAT(ISP))
      FTAB(I,16)=FTAB(I,16)+FTAB(I,3 )*FTAB(I,5 )*(1./FLOAT(ISP))
  301 CONTINUE
      DO 403 K=1,100
C   ** CHECK ORDER ARRAY TO DETERMINE IF PURCHASED PARTS ORDERS HAVE
C      ARRIVED DURING THE DAY-UPDATE INVENTORY AND ZERO ORDER(K,J).
      JTP=ORDER(K,3)
      IF (JTP.EQ.0) GO TO 403
      IAL=ALT(K)
      ALTD=ALT(K)-FLOAT(IAL)
      AJTP=FLOAT(JTP)+ALTD
      AKTP=FLOAT(KTP)+FLOAT(JR5)/FLOAT(ISP)
      IF (AJTP.GT.AKTP) GO TC 403
      SIZ=ORDER(K,2)
      KK=ORDER(K,1)
      FTAB(KK,8)=FTAB(KK,8)+SIZ
      FTAB(KK,5)=FTAB(KK,5)+SIZ
      FTAB(KK,15)=FTAB(KK,15)-SIZ
      WRITE (6,500) K,KK,SIZ,JR5
```

```
      UCOST=FTAB(KK,  )
      IF (FTAB(KK,9).LE...) GO TO 1313
      IF (SIZ.G..FTAB(KK,9)) UCOST=FTAB(KK,11)
 1313 COST(KK)=SIZ*UCOST+COST(KK)+FTAB(KK,4)
      HRT=HRT+SIZ*UCOST
      ORDER(K,1)= .
      ORDER(K,2)=0.
      ORDER(K,3)= .
  4 3 CONTINUE
  2   CONTINUE
      SSC=0
C     THIS DETERMINES THE SHIFT CHANGE COST.
      DO 149 I=1,J5
      IF (OHR(I,1).LT...) GO TO 149
      IF (MS(I).NE.NMS(I)) SSC=SSC+SC
      NMS(I)=MS(I)
  149 CONTINUE
      ITDUM=T-1
C     THIS WRITES THE STATUS OF THE PRODUCTION SYSTEM AT THE END OF
C                                 THE WEEK.
      CALL WRITE (RMC , NMS,APPLY,FTABS,FTAB,PST,RMR,OHR,Q,HOLD,MW,OHRP,
     1OHRM,ALT,COST,      ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I50,J50,J40,
     2W,NOO,LO,UT,SUTCT,TA,ICT,OM,IDLE,OMI,OHJ,OMJ,IDIC,SK,INTCT,MS,ISP,
     3ITDUM)
      WRITE (6,132)
C     THIS WRITES THE IDLE TIMES AND COSTS FOR EACH WORK STATION.
      DO 155 I=1,J50
      IF (IDLE(I).EQ. ) GO TO 155
      WRITE (6,1 3) I,IDLE(I),OMJ(I),OMI(I)
  155 CONTINUE
C     THIS DETERMINES THE TOTAL IDLE TIME AND COST OVER ALL WORK
C                                 STATION.
      ISUM=
      DO 156 I=1,J50
      ISUM=ISUM+IDLE(I)
      O=O+OMI(I)
      AIDL=AIDL+OMJ(I)
  156 CONTINUE
      IDL=ISUM
      BC=AIDL+O
      WRITE (6, 34) ISUM,AIDL,O,BC
      WRITE (6,135)
      ITTA=0.
C     THIS WRITES THE SET UP COST AND SHUT DOWN TIME FOR EACH WORK
C                                      STATION.
      DO 186 I=1,J50
      WRITE (6,187) I,SUTCT(I),TA(I)
      ITTA=ITTA+TA(I)
  186 CONTINUE
      RETURN
C
  158 FORMAT (3I5)
  159 FORMAT (7I10)
  160 FORMAT (3F10.0,F10.0)
  161 FORMAT (4F   . )
```

```
162 FORMAT (5I 0)
163 FORMAT (1H ,4 X,*PRODUCTION ORDERS, TIME AVAILABLE AND ERRORS*/1X,
   14 X,4 (1H*)///)
164 FORMAT (2I )
165 FORMAT (1H ,5 ,*STOCK NUMBER*,I5,5X,*HAS NO FIRST WORK STATION ...
   1 ORDER FOR *,I ,*BATCHES*)
166 FORMAT(1H ,5X,*STOCK NUMBER*,I5,*DOES NOT EXIST ... ORDER FOR *,
   1I ,*BATCHES*)
167 FORMAT (5X,*INITIAL QUEUE FULL FOR STOCK NUMBER  *,I5,* ... ORDER
   1FOR *,I ,*BATCHES*)
168 FORMAT (I )
169 FORMAT (  ,2I  )
170 FORMAT (1H ,/, X,1 (1H*),*TIME AVAILABLE AT WORK STATION *,I3,2X,
   1*GREATER THAN THREE SHIFTS - THREE SHIFTS ASSUMED*)
171 FORMAT (1H ,/, X,1 (1H*),*TIME AVAILABLE AT WORK STATION *,I3,2X,
   1*LESS THAN ONE SHIFT - ONE SHIFT ASSUMED*)
172 FORMAT (5X,*WORK STATION*,2X,I4,*DOES NOT EXIST*)
173 FORMAT (1H ,/, X,1 (1H*),*TIME AVAILABLE AT WORK STATION *,I3,2X,
   1*NOT GIVEN - ONE SHIFT ASSUMED*)
174 FORMAT (I10,4I5)
175 FORMAT (3I10)
176 FORMAT (1H , X,*ALL ORDERS PROCESSED*//)
182 FORMAT (1H ,6 X,*IDLE TIME*,/,61X,9(1H*)///33X,*STATION*,10X,* TIM
   1E*, 0X,*MAN*, ,*MACHINE*,/,39X,*NUMBER*,11X,*IDLE*,9X,*COST*,10X
   2, X,*COST*/)
183 FORMAT (38X,I5, Y,I5,4X,F1 .2,5X,F1 .2)
184 FORMAT (1H ,27X,*TOTALS*,16X,I1 ,5X,F9.2,5X,F9.2,5X,F1 .2)
185 FORMAT (1H ,56X,*WORK STATION DATA  */57X,17(1H*)//39X,*WORK STATI
   1ON*, X,*SETUPS*,18X,*SHUT-DOWN*//)
187 FORMAT (4 X,I ,18X,I4,2 X,I4)
188 FORMAT (  ,*PRODUCT NO*,I5,2X,*OUT OF STOCK *,I7,* UNITS ON DAY *
   1,I /)
500 FORMAT (  X,*ORDER NO *,I5,* FOR SN *,I5,* FOR *,F1 . ,* UNITS ARR
   1IVED ON DAY *,I /)
555 FORMAT (3I  )
    END



      SUBROUTINE WRITE6(RMC1,MYS,APPLY,FTAB8,FT4B,PST,RMR,OHR,Q,HOLD,MW,
     1OHRP,OPRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I5 ,J5 ,J4 ,
     2W,NOJ,LO, T,SUTCT,TA,ICT,OM,IDLE,OMI,OHJ,OMJ,IDIC,SK,INTCT,MS,ISP,
     3ITDUM)
C
C  ** THIS IS SUBROUTINE WRITE6. ************************************
C  ** PURPOSE - TO WRITE INTERMEDIATE AND FINAL STATUS OF THE PRODUCTION
C              SYSTEM.
C
      COMMON /CLOJK/  ,ITP,IX,TINC,HRT,OC,SPNLT,US,CMU,CMC,KTP,IP,VOH,
     1PINVTY,SC,PH,  L,CUM,SSC,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
```

```
      DIMENSION PMCL( 29),NMS(  8),APPLY( 29),FTABB( 29),FTAB( 29,19),
     1PST( 29,  5,4),RMR( 29,  5,5),OHR(  8,6),Q(  8,20,3),HOLD(  8,4),
     2MW(  5,4),OHRP( 29),OHRM( 29),ALT(200),COST( 29),ORDER(200,3),
     3A( 3),B( 3),C( 3),D( 3),E( 3),F( 3),G( 3),H( 3),U( 3),AK( 3),
     4S R( 3),AB ( 3),W( 3), SUTCT(  8),TA(  8),IOT(  8),OM(  5),
     5IPL.(  8),OMI(  8),UHJ(  8),OMJ(  3), IDIC(  5),SK(  5),MS(  8),
     6INTCT(  8)
      INTEGER TA,US,PN,QT,TM,PNU,HQ,T,HOLD,SN,Q,SUT,TEMP1,TEMP2,OM,SK,
     1T MP3,SUTCT,TINC,ORDER
      INTEGER PST,RMR
      COMMON /PRODUC/ PN,QT,TM,PNU,HQ,T,SN,SUT,TEMP1,TEMP2,TOC,ISUM,DB
      WRITE (6,19 )
      WRITE (6,177) ITDUM
      WRITE (6,178)
      DO 152 I=1,J51
      DO 151 J=1,LQ
      IF (Q(I,J,1). Q. ) GO TO 151
      IA=Q(I,J,1)
      IB=Q(I,J,2)*IFIX(FTAB(IA,2))
      IC=Q(I,J,3)
      WRITE (6,179) I,IA,IC,IB,J
151   CONTINUE
152   CONTINUE
      WRITE (6,180)
      WRITE (6,178)
      DO 153 I=1,J50
      IF (MW(I,1).LE. ) GO TO 153
      I3=MW(I,1)
      I6=IFIX(FTAB(I3,2))*MW(I,4)
      IF (I6.LE.0) GO TO 153
      WRITE (6,179) I,MW(I,1),MW(I,3),I6
153   CONTINUE
      WRITE (6,181)
      WRITE (6,178)
      DO 154 I=1,J5
      IF (HOLD(I,2).LE. ) GO TO 154
      I4=HOLD(I,1)
      I6=FTAB(I4,2)*FLOAT(HOLD(I,2))
      IF (I6.L . ) GO TO 154
      WRITE (6,179) I,HOLD(I,1),HOLD(I,4),I6
154   CONTINUE
181   FORMAT (1H0,60X,*HOLD BLOCK    *//)
179   FORMAT (26X,I2, 4X,I5,17X,I5,16X,I5,15X,I5)
177   FORMAT (50X,*WAITING LINES  AT TIME = *,I5//)
180   FORMAT (1H0,50X,*IN PROCESS *//)
178   FORMAT (25X,*WORK *,10X,*STOCK NUMBER*,10X,*ORDER NUMBER*,10X,
     1*QUANTITY*,14X,*POSITION*/23X,*STATION*/)
190   FORMAT (1H1,50X,*STATUS OF PRODUCTION SYSTEM  */53X,27(1H*)///)
      RETURN
      END
```

```
      SUBROUTINE INVENT(RMC1,NMS,APPLY,FTAB8,FTAB,PST,RMR,OHR,Q,HOLD,MW,
     1OHRP,OHRM,ALT,COST,ORDER,A,B,C,D,E,F,G,H,U,AK,SER,ABE,I50,J50,J40,
     2W,NOO,LC,IT,ISP,SUMRY,IROW)
C
C *** THIS IS SUBROUTINE INVENT ****************************************
C *** PURPOSE- TO ACCUMULATE ALL INFORMATION REGARDING INVENTORY AND ALL
C              CONCERNED COSTS.
C
C *** DESCRIPTION OF VARIABLES-
C        APPLY(L) - ACCUMULATED COSTS THAT APPLY TO STOCK NO. L.
C        FTAB8(L) - A RUNNING TOTAL OF THE QUANTITY OF STOCK NO. LTHAT
C                   HAS BEEN PRODUCED.
C
C *** ROUTINES USED-
C       **PICAP**
C
      COMMON /CLCJR/ N,ITP,IX,TINC,HRT,OC,SPNLT,US,CMU,CMC,KTP,IP,VOH,
     1PINVTY,SC,OH,AIDL,CUM,SSC,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
      DIMENSION RMC1( 29),NMS(  8),APPLY( 29),FTAB8( 29),FTAB( 29,19),
     1PST( 29,  8,4),RMR( 29,  5,3),OHR(  8,6),Q(  8,20,3),HOLD(  8,4),
     2MW(  3,4),OHRP( 29),OHRM( 29),ALT(200),COST( 29),ORDER(200,3),
     3A( 3),B( 3),C( 3),D( 3),E( 3),F( 3),G( 3),H( 3),U( 3),AK( 3),
     4SER( 3),ABE( 3),W( 3),SUMRY(  5),15),FCST(3)
      INTEGER TS,US,PN,QT,TM,PNU,HQ,T,HOLD,SN,Q,SUT,TEMP1,TEMP2
      INTEGER PST,RMR
      INTEGER ORDER,TINC
      OSC= .
      UPCOST= .
      EQCOST=0.
      CCOST=0.
      PENALT= .
C
C     THIS SUMMARIZES CERTAIN COSTS, LABOUR AND EQUIPMENT COSTS
C     (OTHER THAN IDLE)  AND THE CARRYING COSTS.
C
      DO 112 L=1,I50
      OSC=OSC+FTAB(L,11)
      UPCOST=UPCOST+OHRP(L)
      EQCOST=EQCOST+OHRM(L)
      CCOST=CCOST+FTAB(L,16)
C
C     THE FOLLOWING STATEMENTS ARE USED TO CALCULATE AND PRINT OUT THE
C     VARIOUS WEEKLY AND CUMULATIVE COSTS.
C
      APPLY(L)=OHRP(L)+OHRM(L)+RMC1(L)+COST(L)+APPLY(L)+FTAB(L,16)
      OHRP(L)=0.
      OHRP(L)=0.
      OHRM(L)=0.
      OHRM(L)=0.
      RMC1(L)=0.
      COST(L)= .
      IF (APPLY(L).EQ.0.) GO TO 112
```

```
112 CO TI.UE
    WRIT_ (J,. )
    WRITE (6,  .)
    DO  .3 M=_,I
    IF (FTAB( ,1). .  .) GC TO 113
    D    KK=  ,
500 FTAB(KK,15)=F   (KK,.7)
    WRIT_ (6,.  )  ,FTAB(M,6),FTAB(M,7),FTAB(M,8),FTAB(M,15),FTAB(M,16
   1),FTAB(M,5),
    FTAB(M,  )= .
    FTAB(M,16)=0.
171 FORMAT (F .0,I ,F  . )
113 CONTI UE
    DO 114 IJK =. ,I
    FTAB(IJK5, )= .
114 FTAB(IJK5, )= .
    WRITE (6, 4)
    WRITE (6, 5) OPCOST
    WRIT_ (6,   ) _.COST
    WRITE (6, 7) OMU
    TCST=OPCOST+ Q OST+OMU
    WRITE (6,.-6) TCST
    C C=CPC+TCST
    WRITE (6, 7) C
    WRITE (6, )
    T C=LQCOST+
    TOC=OPCOST+ I L
    WRITE (6,  ) TOC
    WRITE (6,  ) T C
    WRITE (6, 7) C U
    HC=U +V H*  C
    WRITE (6, ) H
    WRITE (6, 7)  C
    TTC=TMC+  +  +  C+
    W    (6,  )   C
    TO =TOM+T
    WRITE (6,  7)
    WRITE (6,  )
    WRITE (6,  )
    WRITE (6,  ) C ST
    WRITE (6,  )  C
    TIC=UC+CC  T+
    WRITE (6,  )  C
    TDI=TDI+TI
    WRITE (6,  )  I
    VOI=0.
    DO  .7  =.,I
217 VOI=VOI+FT  ( , )*FT  ( ,5)
    XCESS=0.
    IF (VOI.GT.P  Y) XC SS=VI VP*(VOI-PINVTY)
    ALTP N=
5000 CONTINUE
    IF (PENALT.L . .)   TC   .
    ALTPEN=PENALT
    GO TO 5
```

```
 5    PMALT=ALT
      SPMLT=SPMLT+P  LT+XC-SS
      P  PRD=PM LT+XOISS
      WRI     (   .0)
      TPC=TTC+TIC
      WRIT  (   7 )  TPC
      CUM=CUM+TPC
      WRIT  (   7 )  CUM
      WRITE (   9)  HPT
      WRIT  (    )  VOI
      SCORE=CUM+SP LT
      WRIT  (    7)  P  PRD
      WRIT  (    7)  SPMLT
      WRITE (   9)  SCORE
      ITOP=ITP-
      WRIT  (      )  ITOP
 1177 FORMAT (1H , X,*PERIOD  UMBER *,I5)
C
C *** CALL RECAP TO SUMMARIZE WEEKLY RESULTS.
C
      CALL RECAP(COST,JSC,TPC,VOI,SCORE,FCST,W,NT,SUMRY,IROW,FTAB,ISP,
     1TIC)
      C   =  .
      HPT=  .
      TC=  .
      SCC=0.0
      RETURN
C
  1 9 FOR  T (4F  .  )
  1 9 FOR  T (4F 0.0)
  122 FOR  T (   .  )
  1 9 FORMAT (     ,1  ,  X,F   .2)
  13  FOR  T (      *  UNAPPLIED COST HELD BACK*)
  131 FOR  T (      ,*INV  TORY STATUS*,/,59X,16(1H*)///)
  132 FORMAT (   ,*  *,  ,*UNIT COST*,  X,*ISSUES*,  X,*RECEIPTS*,9X,*ON
     1ORDER*,  ,*    Y COST*,7 ,*STOCK ON HAND*,7X,*SN*,/)
  133 FORMAT (7  ,I   ,   ,F   ,  (7X,F1  .2),7X,F   .4,8X,F   .2,3X,I4)
  134 FOR  T (    ,   ,*COST R-PORTS*,/,60X,12(1H*),16(/),53X,*DIRECT
     1M  UFACTURING COSTS*,//)
  135 FOR  T (    ,   ,*LABOR C ST (NOT IDLE)*,4X,F   .2)
  136 FOR  T (    ,   ,*MACHINE COST (NOT IDLE)*,2X,F10.2)
  137 FOR  T (    ,   ,*MATERIALS USED COST*,6X,F10.2,/)
  138 FORMAT (    ,    ,*TOTAL THIS PERIOD*,  X,F1  .2)
  139 FORMAT (   ,   ,*TOTAL TO DATE*,  X,F15.2)
  14  FORMAT (      ,*TOTAL MANUFACTURING COSTS*///)
  142 FORMAT (    ,    ,*TOTAL LABOR COST*,9X,F10.2)
  143 FOR  T (    ,    ,*TOTAL MACHINE COST*,7X,F1  .2)
  144 FORMAT (    ,   ,*OVERHEAD*,17X,F1  .2)
  145 FORMAT (    ,   ,*SHIFT CHANGE COST*,5X,F10.2)
  146 FORMAT (   ,   ,*TOTAL THIS PERIOD*,  X,F10.2)
  147 FORMAT (1H ,  ,*TOTAL TO DATE*,  X,F15.2//)
  148 FORMAT (  ,51 ,*INVENTORY COSTS*//)
  149 FORMAT (1H ,   ,*V LUE OF MATERIALS RECEIVED THIS PERIOD  *,5X,
     1F10.2)
  15  FORMAT (1H ,   ,*  RDER COST*,15X,F1 .2)
```

```
[illegible] FORMAT ([illegible],*CARRY C[illegible]ST*,15X,F1[illegible].2)
[illegible] FORMAT ([illegible],*OUT OF [illegible]TOCK COST*,[illegible]X,F[illegible])
15[illegible] FORMAT ([illegible],7 ([illegible]H*)//)
154 FORMAT ([illegible],*TOTAL PLANT COST THIS PERIOD*,17X,F15.2)
155 FORMAT ([illegible],*TOTAL PLANT COST TO DATE*27X,F[illegible]5.2)
156 FORMAT ([illegible],*CURRENT TOTAL VALUE OF INVENTORY  *,11X,F1[illegible].2)
157 FORMAT ([illegible],*PENALTY AND EXTERNAL COSTS THIS PERIOD  *,5X,
   [illegible])
15[illegible] FORMAT ([illegible],*TOTAL PENALTY AND EXTERNAL COSTS TO DATE  *,[illegible]X,
   [illegible])
159 FORMAT ([illegible],//////,[illegible],*TOTAL SCORE TO DATE   *,[illegible]1X,F15.2)
160 FORMAT ([illegible],[illegible],[illegible]9([illegible]H*)//57X,*COST SUMMARY REPORT*//57X,19(1H*)//)
    [illegible]





    [illegible] R[illegible]CAP(CCOST,U[illegible]C,TPC,VOI,SCORE,FCST,W,[illegible]T,SUMRY,IROW,
   [illegible]
C
C *** THIS IS SUBROUTINE RECAP *******************************************
C *** PURPOSE - TO STORE FINAL RESULTS FOR EACH PERIOD.
C
      [illegible] /CLOJR/ [illegible],ITP,IX,TINC,HRT,OC,SP[illegible]LT,US,CMU,CMC,KTP,IP,VOH,
     [illegible]INVTY,SC,[illegible]H,[illegible]DL,CUM,SSC,TDI,TDM,IFTP,IDL,ITTA,VINVP,N,DUM
      [illegible](3),FCST([illegible]),SUMRY(5[illegible],[illegible]5),FTAB(29,19)
      [illegible]
C
C *** [illegible]L EXECUTION OF THE SIMULATOR, A SET OF 15 VALUES
C     [illegible] PLAC[illegible] SUMMARY TABLE FOR EACH WEEK OF SIMULATED
C                                 OPERATION
C
C *** THI[illegible] WEEK NO. (ROW NO.) FOR STORING THE NEW
C                       SUMMARY DATA.
C
      I=[illegible]-I[illegible]
      WRITE ([illegible])
  [illegible] FORMAT ([illegible],*SIMULATION NUMBER *,I5)
      SUMRY(I,[illegible])=[illegible]
      SUMRY(I,[illegible])=CCOST
      SUMRY(I,[illegible])=[illegible]
      SUMRY(I,[illegible])=TPC
      SUMRY(I,[illegible])=[illegible]
      SUMRY(I,[illegible])=VOI
      SUMRY(I,[illegible])=SP[illegible]LT
      SUMRY(I,[illegible])=SCORE
      SUMRY(I,[illegible])=F[illegible]T([illegible])
      SUMRY(I,[illegible])=W([illegible])
      SUMRY(I,[illegible])=FT[illegible]([illegible],[illegible])
      SUMRY(I,[illegible])=TI[illegible]
      SUMRY(I,7)=IT[illegible]*I[illegible]P-I[illegible]L
```

```
      SUBROUT[illegible] R[illegible](IX,RA,[illegible])
C
C *** THIS IS SU[illegible] RA[illegible] ***************************************
C *** PURPOSE - TO [illegible]RAT[illegible] RA[illegible]DOM NOS.
C
      XI=FLOAT([illegible])*[illegible].0E-7
      X[illegible]=WNDY[illegible](XI)
      CALL [illegible]NDY[illegible](X[illegible])
    4 R[illegible] =[illegible]Y[illegible]([illegible])
      I[illegible].LE.[illegible] -2[illegible]) GO TO 4
      R[illegible]=[illegible]Y [illegible]
      I[illegible]=[illegible]
      R[illegible]
      END
```

****

PROGRAM FOR CORRELATION AND SPECTRAL ANALYSIS

****

```
C
C *** THIS PO3RAM IS USED IN APPENDIX A.
C *** THIS IS PRIMA PRUGRAM ***************************************
C     PURPOSE - TO TEST DATA FOR CORRELATION AND SPECTRAL ANALYSIS.
C
C *** DESCRIPTION OF INPUT PARAMETERS -
C          JX(L,I) - PAST DEMAND HISTORY.
C            L= VARIABLE NO.
C            I= SAMPL  NO.
C          NSAMP - NO. OF SAMPLES.
C       FOR AUTOCORRELATIN NVAR = 1.
C          MLAG - MAXIMUM LAG NUMBER (BETWEEN NSAMP/20 TO NSAMP/2).
C
C *** DESCRIPTION OF VARIABLE -
C          TP(I) - SUM OF VARIABLE JX TILL PERIOD I.
C          FP(I) - SUM OF VARIABLE JX TILL PERIOD I+IP.
C          SP(I) - SUM OF SQUARE OF JX TILL PERIOD I.
C          GP(I) - SUM OF SQUARE OF JX TILL PERIOD I+IP.
C          CP(I) - SUM OF PRODUCT OF JX TILL PERIOD I AND I+IP.
C          RP(I) - SERIAL CORRELATION COEFFICIENT BETWEEN VARIABLE JX(I)
C                  AND JX(I+IP).
C            WHERE  IP=P=LAG NO. (.,1,2,...,MLAG).
C          WP(I) - AUTOCOVARIANC  FUNCTION OF ORDER I.
C          FLP(I) - RAW ESTIMATE OF OF A TRUE POWER SPECTRAL DENSITY
C                   FUNCTION OF HARMONIC NUMBER I.
C          UP(I) - SMOOTH ESTIMATE OF A TRUE POWER SPECTRAL DENSITY
C                  FUNCTION OF H RMONIC NUMBER I.
C          AVEG - MEAN VALUE OF RP(I).
C          SIGMA - STANDARD DEVIATION OF RP(I).
C          FREQ - FREQUENCY.
C          CORNU - NUMBER OF DEGREES OF FREEDOM FOR SPECTRAL CALCULATION.
C          OFFAR - MEAN VALUE OF SMOOTH SPECTRAL DENSITY FUNCTION.
C
      DIMENSION FMT( ),X( ,1 ),TP( ),SP( ),FP( ),GP( ),
     1CP( ),WP(1 ),RP( ),UP(100),FLP(100),TITLE(20),JX( ,100)
      READ 600,TITL
      READ 1,NSAMP,NVAR
    1 FORMAT(2I )
      PRINT 700
      PRINT 600,TITLE
      PRINT 7
  6   FORMAT(   )
```

```
700 FORMAT(1X,(120(1H*))/)
    IF(NVAR) 2 ,2  ,2 .
2   NVAR=1
2 1 CONTINUE
    READ  ,((JX(L,I),I=1,NSAMP),L=1,NVAR)
  4 FORMAT(121 )
    DO    L=1,NVAR
    DO    I=1,NSAMP
    X(L,I)=JX(L,I)
    CONTINUE
    N=NSAMP+1
    AVEG=-1./(FLOAT(NSAMP)-1.)
    SIGMA=SQRT(FLOAT(NSAMP)-1.)/FLOAT(NSAMP-1)
    TWOSIG= .96*SIGMA
    CORUP =AVEG+TWOSIG
    CORLOW=AVEG-TWOSIG
    PRINT 101,AVEG,SIGMA,TWOSIG,CORUP,CORLOW
101 FORMAT (//1X,*PARAMETERS FOR CORRELOGRAM*//5X,*MEAN =*,F10.6,*  ST
   1D. DEV. =*,F1 .6,*  TWO SIGMA =*,F1 .6,*  UPPER LIMIT =*,F10.6,
   2*  LOWER LIMIT =*,F10.6//)
 15 CONTINUE
    READ 3,MLAG
  3 FORMAT(I5)
    IF(MLAG.LE.0) GO TO 400
    DO 100 IX= ,NVAR
    DO    IY=1,NVAR
    TP(1)=0.
    SP( )=0.
    FP( )=0.
    GP( )= .
    DO    I=1,NSAMP
    SP( )=SP( )+X(IX,I)**2
    TP( )=TP( )+X(I ,I)
    GP( )=GP( )+X(IY,I)**2
    FP( )=FP( )+X(IY,I)
 16 CONTINUE
    M =MLAG+1
    DO    I=2,M
    J=I-1
    K=NSAMP-I+2
    TP(I)=TP(J)-X(IX,J)
    SP(I)=SP(I-1)-X(IX,J)**2
    FP(I)=FP(J)-X(IY,K)
    GP(I)=GP(I-1)-X(IY,K)**2
 20 CONTINUE
 23 MLAG1=MLAG+1
    DO    I=1,MLAG
    NMINP=NSAMP-I+1
    CP(I)=0.
    DO 26 J=1,NMINP
    K2=J+I-1
 26 CP(I)=CP(I)+(X(IX,K2)*X(IY,J))
    WP(I)=CP(I)/(FLOAT(NMINP))
    RNUM=FLOAT(NMINP)*CP(I)-FP(I)*TP(I)
    RDEN1=SQRT((FLOAT(NMINP)*GP(I))-FP(I)**2)
```

```
      RDEN2=SQRT((FLOAT(NMINP)*SP(I))-TP(I)**2)
   10 RP(I)=RNUM/(RDEN1*RDEN2)
      IF(IX-IY) 202,203,202
  202 PRINT 150,IX,IY
  150 FORMAT( X,*CROSS CORRELATION X=*,I4,* Y= *,I4//5X,*P*,7X,*SUM X*,
     1   X,*SUM Y*,  X,*SUM X SQ*,11X,*SUM Y SQ*,11X,*C PROD*,13X,*R COEF
     2*/)
      GO TO 204
  203 PRINT 99,IX,IY
   99 FORMAT (//1X,*AUTOCORRELATION X=*,I3,*  Y=*,I3//5X,*P*,7X,*SUM X*,
     1  X,*SUM Y*,  X,*SUM X SQ*,  X,*SUM Y SQ*,1 X,*C PROD*,13X,*R COEF
     2*/)
  204 CONTINUE
      DO 50 I=1,MLAG1
      IP=I-1
   50 PRINT 100,IP,TP(I),FP(I),SP(I),GP(I),CP(I),RP(I)
  100 FORMAT( 4G,I5,5 9.0,F16.8)
      MLAG1=MLAG-1
   33 DO 39 I=1,MLAG
      FLP(I)= .
      DO 36 J=2,MLAG
   36 FLP(I)=FLP(I)+ .0*WP(J)*COS(3.1415927*FLOAT((I-1)*(J-1))/FLOAT(
     1MLAG))
   39 FLP(I)=FLP(I)+WP(1)+WP(MLAG1)*COS(3.1416 *FLOAT(I-1))
      UP(1)=0.46*FLP(1)+.54*FLP(2)
      UP(MLAG1)=0.46*FLP(MLAG)+.54*FLP(MLAG1)
      DO 43 I=2,MLAG
   43 UP(I)= .23*FLP(I-1)+.54*FLP(I)+.23*FLP(I+1)
      PRINT 98,IX,IY
   98 FORMAT (//1X,*SPECTRAL ANALYSIS OF*,I3,*  VS*,I3//*     P*,7X,*COV
     1AR*,  X,*RAW  SPECTRA*,5 ,*SMOOTH SPECTRA*,5X,*FREQUENCY*//)
      TOTUP=
      DO 75 I=1,MLAG1
      IP=I-
      FREQ=FLOAT(IP)/(2.*FLOAT(MLAG))
      TOTUP=TOTUP+UP(I)
   75 PRINT 100,IP,WP(I),FLP(1),UP(I),FREQ
      DORNU=(2.*FLOAT(NS MP)/FLOAT(MLAG))-2./3.
      GFBAR=TOTUP/FLOAT(MLAG1)
      PRINT 102,DORNU,GFBAR
  102 FORMAT (//1X,*PARAMETERS FOR SPECTRAL ANALYSIS*//5X,*NU =*,F16.4,*
     1     MEAN =*,F  . //)
  300 CONTINUE
      GO TO 15
  400 CONTINUE
      STOP
      END
```